FUNDAMENTALS OF AEROSPACE WEAPON SYSTEMS

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Fundamentals of
AEROSPACE WEAPON SYSTEMS

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INTRODUCTION

THE DEFENSE of the United States and the free world during the years when the Air Force ROTC cadets of today will be Air Force officers on active duty will depend upon a variety of complex weapon systems. The specific skills necessary to operate and manage these weapon systems must be developed during full-time active duty service, including attendance at highly specialized technical courses and education by "on-the-job" training. The technological highways to fantastic weapon performance are immediately before us—highways which will assist in finding more effective means of waging land and sea warfare, and making the best possible use of the aerospace to serve the interests of this Nation in particular and the free world as a whole.

An early introduction to the elements of aerospace weapon systems will provide the Air Force ROTC cadet with an orientation to the basic tools which the United States Air Force employs as it accomplishes its mission. No attempt has been made to present more than introductory explanations of the components of the aerospace force which is today's "shield and buckler" against the poised enemy forces. Greater detail would render some portions more complex and voluminous than necessary at this stage of the cadet's educational development. Further, the necessity for safeguarding national security demands that no information of a classified nature may be placed in a publication with such wide dissemination as this book enjoys.

The material to be studied here does not necessarily reflect the latest information. Nowhere in the world today is there subject matter so disposed to change as that dealing with military science. Paradoxically, ceaseless change is the one unchanging quality of modern military science. The very title of this book reflects change; only a few years ago, the coinage word "aerospace" would have seemed strange. The phrase "weapon system" is still somewhat mystifying to most people, even to some in the military profession.

The United States Air Force Dictionary defines "weapon system" as

> A total entity consisting of an instrument of combat (a single unit of striking power), such as a bomber or a guided missile, together with all related equipment, supporting facilities, and services, required to bring the instrument upon its target or to the place where it carries out the function for which built.

This definition, when applied to a single unit of striking power built around an aerospace vehicle, refers not only to the immediately visible components such as the airframe, power plant, fire control system, bombs, navigation equipment, and other concrete evidence readily apparent, but to an entire system, of which the vehicle is only a part.

The phrase "weapon system" came into use in recognition of the extremely complex nature of the measures required to create and deliver certain destructive instruments to their targets. Different systems may be conceived, but they usually involve measures for coordinated action in training, logistic planning, strategic operations, tactical operations, air defense, and transport. Each system

begins with the concept of the instrument of combat itself, leading through its planning, manufacture, testing, and operational stages.

An essential part of the weapon system is the management necessary to assure the validity of each step in the process. When the weapon system concept first came into being there were coordinated efforts to assure a continuous process, with many successive steps. Today, however, the management part of the system has been refined to the point where continuity has given way to concurrency: the overlapping of the research, development, testing, and production phases.

The United States and its free world associates are engaged in a technological contest with Communist imperialism. In such a contest the decisive campaigns are conducted in the laboratory and at the experimental and test facilities.

The weapon system concept is not merely a theoretical approach, nor is it an arbitrary plan decided upon as an innovation for its own sake. It is a concept which was forced upon us by the rapidity with which new developments have been brought into being. It is not so much that there have been changes, but that the changes have occurred at such an increasing rate. The rate of change at which advances are made is so great that planned components of a given weapon system can well become obsolete before the entire system, as planned, can be completed. Consequently, continuing evolution of subsystems must be a recognizable factor during the development of any weapon system, with an overriding need for integration among several weapon systems, if we are to take advantage of the latest available techniques, instruments, materials, and other significant components.

Technological supremacy, within the time limits imposed by technological warfare, is a necessity for the survival of our Nation and our free way of life. Through the facilities of the Air Force Systems Command, and those of the Air Force Logistics Command, Air Force specialists work with the best industrial scientists of the Nation to bring into being the most advanced instruments of national security possible. Eighty percent of the funds spent by the Air Force Systems Command in direct research and development are allocated to contracts with universities and industrial organizations whose technological competence can be demonstratively utilized to the greatest possible advantage to support the weapon system concept.

The contents of this book have been compiled as a survey of present aerospace weapon systems and their use by the United States Air Force in its assigned role as guardian of the security of the free world. No attempt has been made to delve into the complexities of the research, development, production, and procurement of the material components of the weapon systems. Nor has any effort been made to attempt even an outline of the extensive personnel education and training complex which prepares the human element to take its place in the over-all system.

The text is a basic introductory orientation to the fundamental components of aerospace weapon systems as they exist in the United States Air Force. These include the warheads whose delivery is the ultimate purpose of a weapon system, the manned and unmanned delivery vehicles through which they are brought in contact with the enemy, the means by which these vehicles travel, the principles of the control and guidance systems which direct them in their travels, and the major categories of destructive effects they bring to bear.

After presenting the principles underlying the material components, consideration is given to the actual operations in which they are used, including the selection of enemy targets, offensive and defensive electronic aids which serve the vehicles and weapons in flight, and the organization and theories involved in actual defensive, strategic, and tactical operations.

The text concludes with a look into the future, providing some fundamentals of astronautics. Two appendices have been provided as references for comparative specifications of manned operational aircraft of the United States Air Force, and the best known missiles.

This book is a survey, and as all surveys must be, it is incomplete. It cannot be considered as a final authority in any sense. Even while this book was in the process of printing and binding, new advances were being made in technology. The arsenal of aerospace weapon systems is constantly being enlarged and improved. The Air Force ROTC cadet, who may expect to take his place among his fellow Americans who are at this moment already serving the cause of the free world on active duty with the United States Air Force, has an obligation to familiarize himself with the principles outlined in the following pages, and to further his aerospace education by constant references to current publications which present authoritative information on the latest developments.

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CHAPTER 1

WARHEADS

Warheads constitute the reason for military weapon systems as we know them today. In any form of combat, whether individual or worldwide, the immediate intent is to disable the opponent before he disables you. Except in hand-to-hand combat, where the disabling instrument is retained by the user (e.g., a fist, a hand-held club, or a knife blade), the instrument is normally made to travel from the person of the user to the person of the opponent over distances varying from a few feet, or even inches, to many thousands of miles. The actual

◀ **Air Force armament technicians install the warhead on TM–61 Matador missile in Formosa.**

instrument which disables the opponent is the warhead. It may be a rock, arrowhead, spearhead, bullet, hand grenade, or nuclear bomb.

Some years ago, the Air Force utilized a greater variety of types and kinds of bombs and fuzes. Today, a streamlining has taken place in all fields, including the airmunitions area. Certain types of bombs have been declared obsolete, others "limited standard," and still others carry a security classification. Fuzes have been refined and more standardized. Also, both bombs and fuzes have been designed so that each may be adapted to newer developments. Consequently, this chapter is limited to the explosive and chemical type bombs and their fuzes, along with the currently standard rocket used by the Air Force.

After the warhead has been installed in a bomb or missile, some means must be used to protect personnel from a premature explosion. Protection is achieved by an arming circuit. There are various types of such circuits. A shorting plug, or shorting bar, can be used to keep the circuit inactive while the missile is fired; as the missile or bomb breaks contact with the launcher, the shorting device can be automatically pulled loose, thereby arming the warhead. Arming the warhead means putting the warhead in condition to detonate when the missile or bomb hits the target.

BOMBS

A bomb is a kind of ammunition designed to be dropped from an aircraft to inflict damage on enemy personnel and materiel. The typical aircraft bomb consists of a metal container filled with explosives or chemicals, a device for stabilizing the bomb so that it can be aimed accurately, a mechanism for exploding the bomb at the target, and necessary safety devices to make it reasonably safe to carry. The metal container, called the bomb body, is usually streamlined, with an ogival (pointed arch) nose and a tapered tail. The stabilizing device—generally a sheetmetal fin assembly—is attached to the tail end of the body. Some bombs utilize a parachute or cloth streamers for stabilization purposes. The fuze mechanism used for exploding the charge may be placed in either the nose or the tail of the bomb body. In some cases, fuzes are placed in both the nose and the tail to make certain that the bomb explodes—if one fuze should fail to function, the other fuze will insure detonation.

In common with other types of ammunition, bombs are classified according to their use, and according to filler. They are classified according to use as general purpose (GP), fragmentation, gas, incendiary, smoke, photoflash, target identification, drill, practice, nuclear, biological, and radiological. Except for practice bombs, they are classified according to filler as explosive, chemical, pyrotechnic, inert pathogenic microorganism, fissionable, fusionable, and radioactive HE material. Under the explosive classification are general purpose, fragmentation, and demolition bombs. Under the chemical category are gas, smoke, and incendiary bombs. Photoflash and target identification bombs fall into the pyrotechnic classification.

Bombs and their components are identified by standard nomenclature, federal stock numbers, and the ammunition lot number which are stenciled and stamped on all packings and, where size permits, on the item itself.

High Explosives

A high-explosive warhead may be designed to produce such varied results as destruction by concussion (blast effect) or destruction by fragmentation (effect from the fragments projected from the warhead casing at high velocity).

High-explosive material housed in a metallic case produces blast effect. Target damage is caused by a pressure wave which is set up in the air or other surrounding medium by the force of the explosion. This wave is somewhat analogous to the wave produced when a large stone is dropped into a pool of water. This type of warhead has been successfully used against aerial targets, although the higher the altitude, the less dense the air and the less damaging the resulting pressure wave.

The fragmentation warhead uses the force of an explosive charge to project metallic fragments of the casing at high velocity to damage the target. The size and velocity of fragments and the spray pattern they form can be controlled by

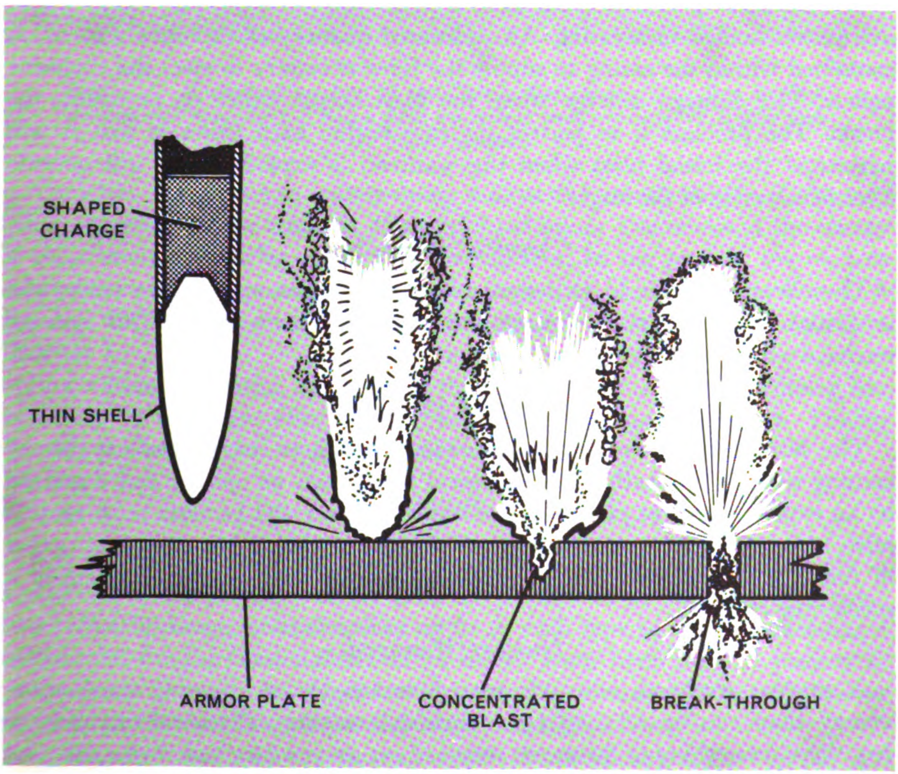


FIGURE 1. Action of a shaped charge when it strikes the target.

variations in the design and construction of the warhead, and they are influenced by the point of detonation. The size of the fragments is controlled by weakening the metal casing at selected points, causing fractures to occur at these points when the warhead explodes. The velocity of the fragments is controlled by the type of explosive used and the explosive-to-metal ratio. Performance of the fragmentation warhead is limited by the amount of metal available to form fragments and by the amount of explosive available for breaking the metal into fragments and giving them the necessary velocity.

Aerial targets are more susceptible to damage by fragments if the warhead explodes at an optimum distance from the target. The fragmentation warhead is also more effective against partially protected surface targets when exploded in the air above the target than when exploded on the surface near the target.

Warheads made with a shaped charge show considerable promise in both surface-to-surface missiles and surface-to-air missiles. This warhead consists of a casing containing highly explosive materials. The explosive charge is designed to be parabolically hollow at the nose, the hollow causing blast to take a desired direction when the charge is detonated. The shaped charge diagrammed in Figure 1 is most widely used against armored surface targets. The antitank bazooka rocket used during World War II used the shaped charge.

The explosive-pellet warhead consists of a group of separately fuzed explosive pellets housed in a casing. An additional quantity of explosive material is contained within the casing to supply the force necessary to eject the explosive pellets. The damage is large when the blast occurs either on or within the target. The problem is to perfect the fuze within each pellet so that it will withstand the initial blast when the warhead is exploded and will operate after penetration of the target.

Chemical Warheads

The chemical warhead is designed to produce personnel casualties by the inhalation of, or physical contact with, a poisonous material. This type of warhead will be studied in a later chapter.

Biological Warheads

The biological warhead contains living organisms, or agents, capable of causing sickness or death. The biological agents can be ejected and dispersed by an explosive charge placed in the warhead. Since the bacteria must remain alive to be effective, special care must be given to the design and construction of this type of warhead. These agents will be discussed at greater length in a succeeding chapter.

Nuclear Warheads

A nuclear warhead, when detonated, is capable of releasing much more energy than can be released by a chemical reaction. Chemical changes, or reactions, do nothing to the atoms involved except combine them with different atoms in a different way. Nuclear reactions get their energy from changes in the nucleus, which are the bases of the power of the nuclear bomb. Although

the Hiroshima bomb was equivalent to about 20,000 tons of TNT, only a very small quantity of fissionable material was used (Fig. 2). Later developments made a far more powerful bomb possible—the fusion bomb.

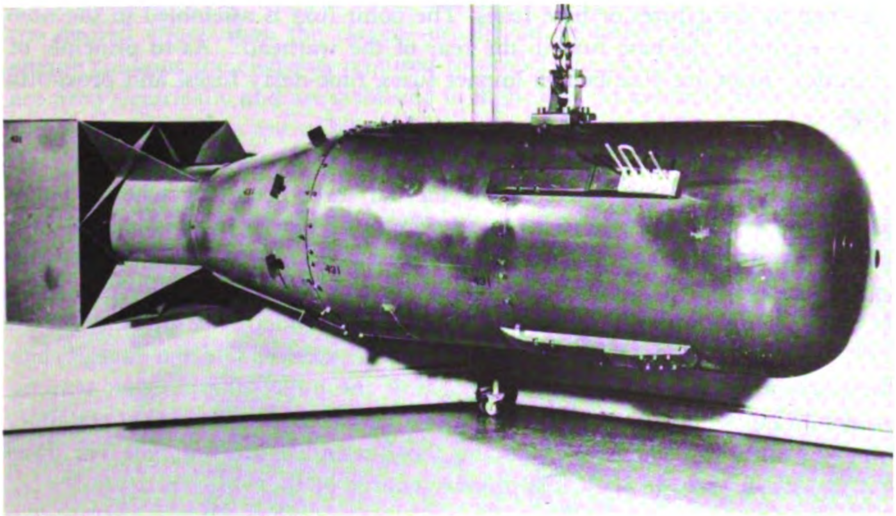


FIGURE 2. A nuclear weapon of the "Little Boy" type. The first nuclear weapon ever detonated, it had a yield equivalent to approximately 20,000 tons of high explosive.

A nuclear explosion can scatter many radioactive atoms which will damage living organisms by the emission of harmful radiation. The source of the energy of these emitted particles comes from the nucleus. In the process, the nucleus loses some of its mass and an equivalent amount of energy is released. A detailed discussion of nuclear energy and its use in weapons will be found in Chapter 7.

In a nuclear explosion, as well as in the other types of explosions, timing has much to do with the effect that the warhead has on the target. Timing depends on the fuze used to detonate the warhead.

FUZES

A fuze may be defined as a device designed to activate the main charge in a warhead at the proper time for producing a desired damage to a particular target. Special design considerations apply to each type of fuze. Surface-based targets call for the least differences in design from fuzes used at present in conventional weapons. But fuzes for the warheads of missiles to be used against aerial targets present the greatest difficulties in design.

Fuzing of a warhead depends upon the characteristics of the target, the attacking aerospace vehicle, and the type of warhead. It must also take into consideration the location, vulnerability, speed, and physical structure of the

target, along with the capabilities of the attacking vehicle and warhead, in order to make the probability of damage to the target as high as possible.

Fuzes can be classified either according to their position in the warhead or according to the principle upon which they operate. As to position, fuzes are classified as point fuzes or base fuzes. The point fuze is assembled in the nose of the warhead, the base fuze in the rear of the warhead. As to principle of operation, fuzes are classified as impact fuzes, time-delay fuzes, and proximity fuzes.

Impact Fuzes

An impact fuze is actuated by the inertial force occurring when a bomb or a missile strikes a target. Suppose a cylindrical type of fuze is located in a warhead with a shock-sensitive, explosive percussion charge permanently fixed in the forward end of the tube (aligned longitudinally to the direction of flight). A heavy metallic plunger is installed at the rear end of the tube. While in flight, the movable plunger remains against the rear end of the tube. When the warhead comes to a sudden stop against the target, the plunger, tending to remain in motion, will move with great force to the forward end of the tube, where it will strike and detonate the shock-sensitive fuze charge. The fuze charge will in turn detonate the primary charge of the warhead.

Time-Delay Fuzes

A time-delay fuze is designed to detonate the warhead at some predetermined time after the missile or bomb has been released. The time-delay element usually consists of a watch or clock mechanism. Since the time interval cannot be changed after the bomb or missile is released, this type of fuze is not likely to be used on a guided missile that maneuvers against an aerial target.

Proximity Fuzes

A proximity fuze is actuated by some characteristic feature of the target or target area. Some variations of this type are the variable-time (VT) fuzes. The usable characteristic features of a target or target area may be photoelectric, acoustic (sound), pressure, electromagnetic (radio), or electrostatic.

A fuze of this type is preset to function when its sensory mechanism detects a desired intensity of the characteristic of the target or target area to which the fuze is sensitive. Proximity fuzes are designed to detonate so that the warhead will burst and make its pattern at the best time and location relative to the target.

In general, adapting the proximity fuze to the burst pattern of the warhead is difficult, since this pattern is influenced by the relative velocity with which the warhead approaches the target. Because airborne targets may have a wide range of speeds, it is desirable to adjust fuze sensitivity automatically on the basis of the target speed as predicted by a computer. Proximity fuzes activate the auxiliary warhead-detonating system after electronically integrating two factors: nearness to the target and rate of approach to the target.

AIRCRAFT ROCKETS

A rocket is a missile which is propelled by the reaction of a discharging jet of gas at high velocity. A rocket consists essentially of a head, an engine, and a stabilizing fin (Fig. 3). The head contains the elements necessary to produce the desired effect upon the target—usually an explosive filler and fuzes. The engine contains the elements required to propel the rocket. All aircraft rockets are fired electrically and are stabilized in flight by a fin assembly attached to the rocket. Some rockets are stabilized by a spin action created by the position of the nozzle in the engine.

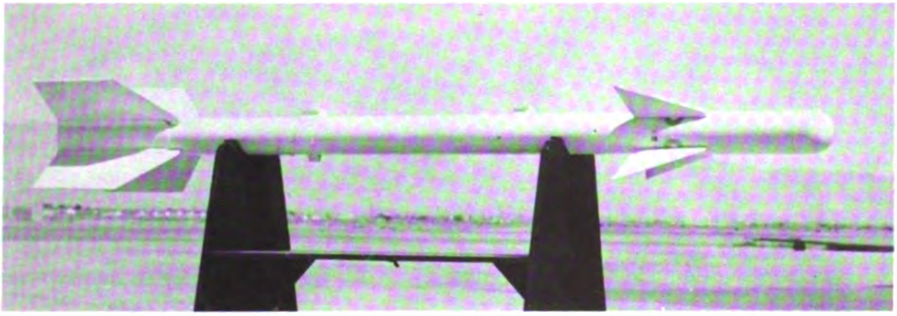


FIGURE 3. Guided by an infrared or "heat seeking" device, the Sidewinder seeks the target by homing on the heat being emitted by the target aircraft.

In order that a rocket may be fired on a desired trajectory, a device called a launcher is required. Aside from providing a means of igniting the rocket, the launcher is also required to carry and aim the rocket. These features make it possible not only to fire rockets from aircraft but also from areas inaccessible to regular artillery. The employment of rocketry is more economical than artillery because rockets are relatively inexpensive, are easily launched, and require fewer personnel to fire.

The 2.75-Inch Folding-Fin Aircraft Rocket (FFAR)

Typical of aircraft rockets is the USAF FFAR. The 2.75-inch-in-diameter FFAR is a folding-fin, high-velocity aircraft rocket which, with the appropriate warhead for the purpose, serves as an air-to-ground, air-to-air, or practice weapon. A fuzed head loaded with high explosive (HE) is available for air-to-air use; a high-explosive, antitank (HEAT) head for air-to-ground use; and an inert practice head with a dummy nose for practice and training.

The rocket engine of the 2.75-inch FFAR is similar to other solid-propellant rocket engines and contains a double-base, ballistite-like, propellant grain. It differs from most other fin-stabilized rockets in having fins which fold within the outside diameter of the rocket and which are forced open by pressure when launched.

At present this rocket utilizes three types of fuzes. They are all detonator-safe and are armed by "set-back" action. ("Set-back" action is a general term

FIGURE 4. Technician puts 2.75-inch Folding-Fin Aircraft Rocket (FFAR) into a wing pod.

applied to devices which utilize tension springs as safety measures; the arming sequence cannot begin until the forward acceleration of the rocket overcomes the resistance of the spring.) No arming wire is required.

The MK–176 fuze is cone shaped to finish the streamlining of the head. It incloses the firing and arming mechanisms, a primer, delay element, detonator, lead-in, and a booster. The MK–178 is the same fuze, except that there is no delay element incorporated. The MK–181 is designed for use with the HEAT head, and it is base, rather than point, detonating.

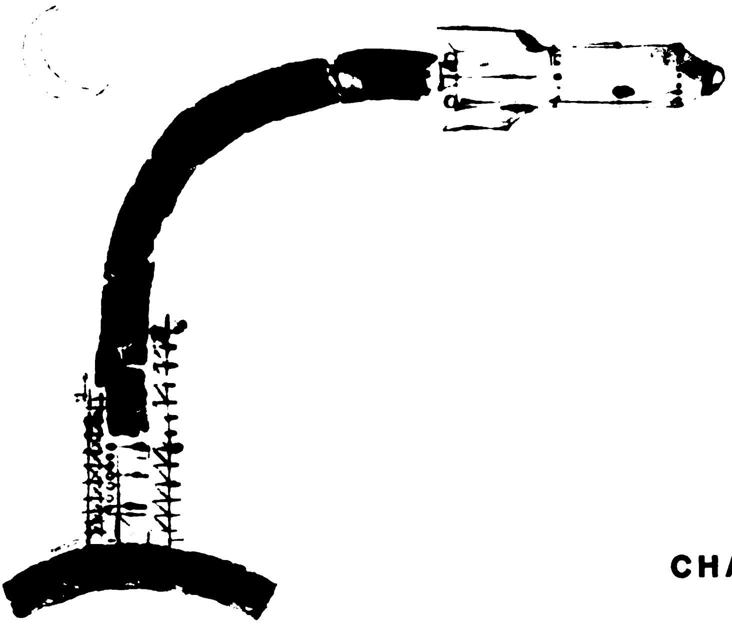
The head is a steel case which carries the explosive, and it is threaded to receive the fuze and to attach it to the motor. A threaded, cup-shaped, fuze cavity liner is screwed into the nose end of the loaded head, and it seats on the forward face of the explosive filler.

It is not possible to discuss the details of other aircraft rockets in this book. Although the basic principles described for the 2.75-inch FFAR apply to other aircraft rockets as well, the details, particularly of the specific guidance systems used, are withheld for security reasons. Unclassified reference to guidance and propulsion systems of rockets and missiles will be made in succeeding chapters.

Missiles may be considered as more advanced types of bombs, or, perhaps, one-way bombers without human crews. The principle remains the same: a combination of bomb (warhead) and delivery vehicle (bomber) into a single instrument (warhead-carrying missile). Although the public generally holds the idea that missiles, particularly ballistic missiles, are all nuclear weapons, the military man realizes that there are many requirements for nonnuclear tipped missiles.

The entire weapon systems of the manned and unmanned delivery vehicles mentioned in succeeding chapters have one essential common element: each has been developed to deliver a selected warhead to whatever location necessary to incapacitate or destroy the enemy. Unless this can be accomplished, all efforts to develop weapon systems have been in vain.

LAUNCHER A B
CAMERA BH 1 2
LAUNCHER A B
CAMERA BH 1 2
CAMERA BH 1



CHAPTER 2

MISSILES

Aerospace Delivery Vehicles

The U.S. Air Force ballistic missile program is the largest military development program ever undertaken by this nation. It involves tremendous simultaneous efforts to advance in many aspects of the missile art. Among the difficulties to be surmounted have been and continue to be those involving the development of rocket engines to produce high engine thrust, equipment to provide greater guidance accuracy, and resistance to extremely high speeds and temperatures. The effort has also required greater expansion of production and testing facilities than has been true in any other military program. Unlike

◀ *In blockhouse at an Air Force space launch facility, technicians watch TV screens to monitor launch pad activities.*

other programs which evolved with multiple stops, starts, and borrowings from other programs, it has been a single, integrated program. From it now emerges the operational weapon systems for use in intercontinental and intermediate-range missile weapons.

PLACE OF MISSILES IN AEROSPACE WARFARE

The capability of the first-generation (i.e., the first operational) ballistic missiles fits neatly into the U.S. philosophy of modern warfare. This philosophy, which has evolved in the United States since World War II, is based upon the ability to mount an immediate and decisive retaliatory attack against enemy forces and his heartland. The philosophy embraces the proposition that the sheer potential destructiveness of such an attack will deter enemy aggression. Since the avowed policy of the United States leaves the initiative in the hands of the enemy, our ability to launch quickly and decisively a counterstrike against the enemy requires a force in being. This ready force must be secure from enemy attack and capable of winning the decisive phase of the war should its deterrent effect fail. Such a force will be an effective deterrent to an enemy only if the enemy has knowledge of the force's capability and invulnerability and, at the same time, knows of the intention to exercise this force.

The primary deterrent to enemy aggression since World War II has been the United States strategic air forces equipped with manned bombers. The deterrent effect of this force is being slowly diminished by improved counter-bomber defenses. The early ballistic missiles, handled properly, have the characteristics to assist in the deterrent task. The manned bomber will be an important part of the total deterrent force for a long time to come, but the first operational ballistic missiles supplement the bomber and help restore the effectiveness of the bomber forces by their capabilities to overcome the counter-bomber defenses. The combination of manned aircraft and unmanned missiles is referred to as a "mixed force."

The relationship of the ballistic missile newcomer to the family of strategic weapons will be determined by its capabilities and limitations. The tremendous speed of the weapon is possibly the characteristic most important to its strategic role. The significant reduction in flight duration and the improved ability to penetrate enemy defense are two attributes of the missile's hypersonic speed which make the missile far superior to aircraft. Hardening (protecting by reinforced concrete or steel, or going underground, or both) and camouflaging the launching site of the missile make it less vulnerable to surprise attack than the large runway complex of the aircraft ground environment (Fig. 5).

Certain operational requirements must be met to capitalize on the advantages of fast reaction and improved ability to penetrate defenses. Some changes in operations or tactics are mandatory. Advance planning and detailed targeting information are of pre-eminent importance. Intelligence information, always a prerequisite for a successful aircraft strike, is most important, since the missile's entire mission will be predicated on this information. Extensive logistic support

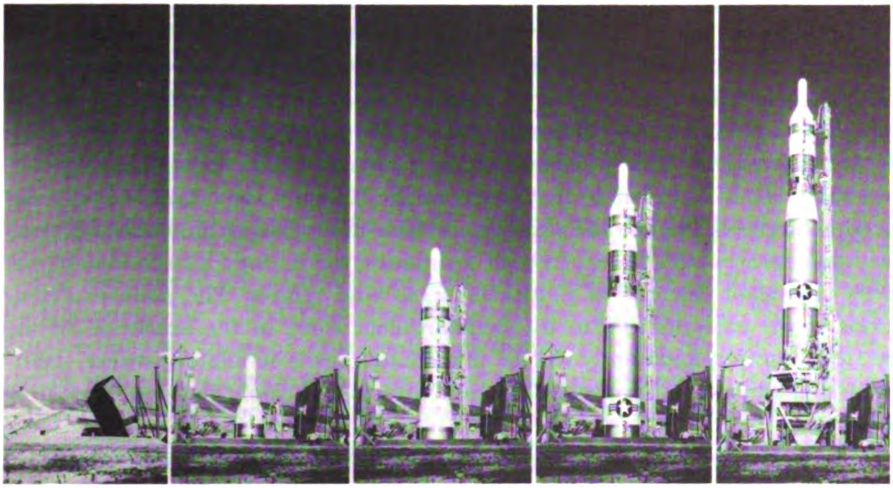


FIGURE. 5. This series of photographs shows the Air Force Titan I Operations Systems Test Facility (OSTF) during a period of a few minutes—from the time the launch controller initiates the launch sequence to the instant just prior to lift-off of the 97-foot, 110-ton intercontinental ballistic missile.

is required. The unusual nature of fuels used, the intricate instrumentation and electronic gear all demand unique facilities and highly skilled personnel. This material and manpower must be prepositioned and made secure to insure prelaunch survivability.

Aside from imposed operational requirements, the ballistic missile has inherent limitations that must be considered for a full appreciation of the missile's initial employment. One such limitation is an inability to attack fleeting targets and targets on which detailed information is lacking. Initially, even its fixed targets will be large-area ones, because of expected inaccuracies in the guidance systems and inexact target information. Selectivity of warhead size to fit the tactical situation will be restricted. It would not be profitable to deliver small-yield warheads, because the use of the totally expendable missile can be economically justified only if the damage effected is in favorable ratio to the cost involved. With its one-shot performance, the weapon will be limited to priority targets commensurate with its delivery yield and guidance accuracy. Also, reliability must not be ignored. Estimates on the reliability of the ballistic missile force vary, and it takes considerable testing and practice to establish a dependability that is termed "combat ready."

Even with its known limitations, the ballistic missile lends itself ideally to some of the missions performed by the long range manned bomber. It appears that within a limited number of years the ballistic missile will become the primary means of conducting offensive strategic operations against an enemy, largely superseding the conventional manned bomber. In the interim, substitution of missiles for the more conventional systems will be made as rapidly as technical progress permits. The transition period will see a gradual change, with

the ballistic missile and the long range manned bomber being used concurrently in the mixed force.

Missile strikes in advance of the aircraft could aid the more accurate manned bomber attack by causing general confusion, disrupting communications, and possibly damaging enemy defenses, particularly point defenses adjacent to the large-area targets. Enemy defenses against aircraft attack are improving considerably. It is conceivable that there might be some important, heavily defended targets that would be almost impossible to destroy with manned bombers without unacceptable losses. In such a situation the ballistic missile may be the only practicable method of destroying these vital targets. The main contributions of the early missiles to the bombardment force in the execution of the strategic mission apparently will be immediate missile retaliatory strikes, assistance to manned-bomber penetration, and attacks on heavily guarded, large-area targets.

Although the eventual long range influence of the ballistic missile on warfare is difficult if not impossible to determine, some reasonable comments on the subject may be made with some assurance. No armament of warfare is ever static in its development or application. The eternal swing of the pendulum from predominance of offensive weapons to counter defensive weapons alone could conceivably render this seemingly master weapon of the future obsolete before it is ever used in warfare. The experience of the British in World War II, when London was finally spared further bombardment by the V–2 only as Allied ground forces overran the launching sites, would seem to contradict this; on the other hand, no one can foresee what developments in the field of countermeasures the space age will bring. In the present stage of development, development of adequate defense against the ballistic missile in flight, with its extremely high altitudes and speeds, appears to be a task of gigantic proportions.

The ballistic missile, in its improved form of several years from now, would seem to give new meaning to at least two principles of war: economy of force and concentration of force. Also, with the large destructive power of the nuclear warhead, the ballistic missile will make possible an orderly neutralization of complete target systems with the utmost economy to friendly forces. The free disposal or placement of forces, a principle of war which can include mobility, flexibility, and surprise, will apparently not change, although the concept of operations will be modified. Because of the weapon's speed, range, accuracy, and payload, any target system selected could be hit with almost any degree of intensity desired. With movement of forces at the rate of some 16,000 miles per hour, the surprise to be effected will be achieved in a matter of minutes.

Initial control of the ballistic missile in this country in the years ahead must be unequivocal and absolute. Any decision to unleash the ballistic missile force can be made by no less a person than the President. Since our national policy is firmly dedicated to preventing war and our military capability geared to reacting against aggression, any decision of this type will undoubtedly come from the President as Commander in Chief, in a situation clearly requiring and receiving public endorsement and Congressional approval. Under condi-

tions of complete surprise attack, national survival will depend upon prearranged rules of engagement as well as upon military readiness.

In any evaluation of the future of the ballistic missile, one fact is clear: the United States must keep as far in advance as possible in the development of both the ballistic missile and the defensive meaures against it. An enemy is not likely to launch an attack that has small chance of a quick success.

MISSILE DEVELOPMENT SINCE WORLD WAR I

The first guided missile was developed and demonstrated in 1918 by Charles F. Kettering. He called this remotely controlled airplane the "Bug." This flying bomb, or "missile," was controlled during its time of flight by mechanisms using the same principles as today, and was deliberately guided in the true sense of the word. Such developments as this opened the way to giving the tremendous power of the rocket an electronic brain to control and direct it.

The German Program of Development

In the period between World War I and II, the pace of guided missile research quickened. The Germans in particular carried on an extensive program, establishing the Peenemunde project in 1936. The long range rocket, which could come into being only after general technological progress had been made in such fields as physics, chemistry, and electrical and mechanical engineering, was developed in Germany in the 1930's and early 1940's. Since the Treaty of Versailles restricted the weapons that Germany could possess, military officials in that country began to search for new types of weapons that could be produced without violating the treaty. Rocket literature and experiments in the field drew attention to rockets, and by 1930 the German Army had embarked upon a research program aimed at the military utilization of rocket propulsion. Attempts to interest German private industry in the program failed in the early stages of the work, largely because the international commitments of industry and the secrecy requirements of the program were incompatible. Military leadership in the program was provided by Maj. Gen. Walter Dornberger, now an executive for Bell Aircraft Corp.; technical direction by Dr. Wernher von Braun, who became technical director of the U.S. Army missile program and later took a similar position with the National Aeronautics and Space Administration (NASA).

Weapon-makers had long conceived of an air-borne weapon with a robot pilot. But not until knowledge and techniques of electronics were expanded to the point required to develop an automatic guidance and control system was the construction of a true missile possible. Aircraft previously had been successfully flown great distances by push-button control from takeoff to landing. This type of control lent itself readily to the missile.

The outstanding German developments in the form of operational missiles were the V–1 and V–2. The V–1 was a small, jet-propelled craft with a wingspan of over 25 feet, launched from an inclined concrete ramp. The engine

burned a low grade fuel oil mixed with atmospheric oxygen, and developed a speed of 400 mph. The range of the V–1 was about 230 miles, carrying a ton of explosive at an altitude of about 3,000 feet. The first of these "buzz bombs" landed in England on June 13, 1944. In all, about 8,500 were launched and about 2,400 reached the target, causing a total toll of killed and seriously injured of about 25,000. The winged V–1 was more properly classified as a pilotless aircraft. The V–2 was a wingless missile using alcohol and liquid oxygen for fuel. Its payload and range were slightly less than those of the V–1, but its speed of one mile per second along its trajectory made it impossible to shoot down en route, as had been the case with the V–1. The only defense against this missile was destruction prior to launch. About 500 V–2's reached London, causing 10,000 casualties.

The Development of Missiles in the United States

Located at considerable distances from potential enemies, the United States devoted much energy before and during World War II to the development of long-range bombers rather than guided missiles. The first guided missiles put into tactical use by the United States during World War II were bombs which were equipped with surface controls attached to the tail and with guidance equipment in the form of a receiver and a transmitter. These were the vertical bomb (VB) series, which included the Azon, Razon, and Tarzon. The Razon and Tarzon did not see actual combat operations. The Azon was a 1,000- or 2,000-pound general purpose bomb guided only in azimuth, or direction (right or left). The Razon was the same type of bomb guided in both azimuth and range (horizontal distance). The Tarzon was a 12,000-pound general-purpose bomb controlled in both azimuth and range. Most of the VB series used high-intensity tail flares to assist the bombardier in guiding them.

The next step was the development of the glide bomb (GB) series. Besides surface controls for guidance, a glide bomb had airfoils or lifting surfaces and, while under control of the bombardier, was made to glide into its target. This greatly increased the range and accuracy of the ordinary bomb. Both the VB and the GB series were dropped from aircraft. Guidance of the GB series was by radio control.

Scientists realized that if a means of propulsion were applied to a glide bomb, its velocity and range could be greatly increased. The version so modified was designated jet bomb (JB). Good examples of jet bombs are the radio-controlled, low-wing Gargoyle (Navy) and the JB–2, the American version of the V–1. Another important development in this type of bomb was the Tiamat (JB–3) rocket propelled, radar-guided AAM.

Near the end of World War II, a second phase of guided missile development in the United States began. This phase lasted well into the postwar period. It was the beginning of an accelerated program, and provided such experimental missiles as the Private and Corporal series. The Private series, models A and F, were used only for investigating missile design and performance characteristics. This development, known as the Ordcit project (Ordnance and

California Institute of Technology), began in January 1944. The Private series were solid-propellant rockets developing about a thousand pounds of thrust for approximately 30 seconds; with special booster rockets at the moment of launch, an initial thrust of 21,000 pounds was generated.

Another missile developed at this time was the Wac Corporal. This vehicle was 16 feet long and 12 inches in diameter. Stabilization consisted of three guide fins instead of the usual four. Its launching weight without booster was 665 pounds. The Corporal used a liquid-fuel rocket engine—the first to use red fuming nitric acid as the oxidizer and gasoline for fuel. But this combination did not perform satisfactorily, and the fuel was later changed to aniline, with the same oxidizer. This latter mixture was much more efficient. The thrust generated by this mixture amounted to 1,500 pounds for a duration of 45 seconds. In the nose section of the Corporal were cameras, meteorological instruments, and a parachute for purposes of recovery. Flight tests were carried out at White Sands Proving Ground, N. Mex., in 1945. The Corporal reached a height of about 43 miles and proved to be an excellent high-altitude research missile.

It was a model of this same Wac Corporal which was used in the record-breaking Project Bumper. In this project, on February 24, 1949, a Wac Corporal, boosted by a modified captured V–2, covered a linear distance of 580 miles at an average velocity of 2,900 miles per hour. During the next few months after this record flight, operations for Project Bumper were moved to the Air Force Missile Test Center at the long-range proving ground in Florida. There, several launchings to study long-range operations were carried out, and ranges of several hundred miles were realized. The V–2's used in these experiments were destroyed at about 16,000 feet on their fall back to earth.

Meanwhile, in order to continue these research studies after the supply of captured V–2's was used, the Aerobee was developed. ("Aero" is the Aerojet Engineering Corp., which was responsible for the complete propulsion system, and "bee" is for its relationship to the Bumblebee projects of the Johns Hopkins University Applied Physics Laboratory) (Fig. 6).

The Aerobee was first fired on November 24, 1947, and proved to be one of the workhorses of high-altitude research. The Aerobee was almost 19 feet long (excluding the booster) and about 15 inches in diameter. The aid of the booster brought the velocity up to 900 feet per second. The most unusual characteristic of the Aerobee was that it had no movable aerodynamic surface controls. The three guide fins were attached rigidly to the body of the rocket. The flight path of the Aerobee depended on "arrow stability." The average altitude reached by this missile was about 70 miles.

Late in 1949, experiments were begun with a new missile called the Viking. It was assembled by the Glenn L. Martin Aircraft Co., Baltimore, Md., and the engine was developed by Reaction Motors, Inc., New Jersey. In general appearance, the Viking was very similar to the V–2. It was over 45 feet long with a diameter of 32 inches; and, for stabilization, it used four fins with a span of slightly over 8 feet. The Viking was designed to carry a 100-pound payload

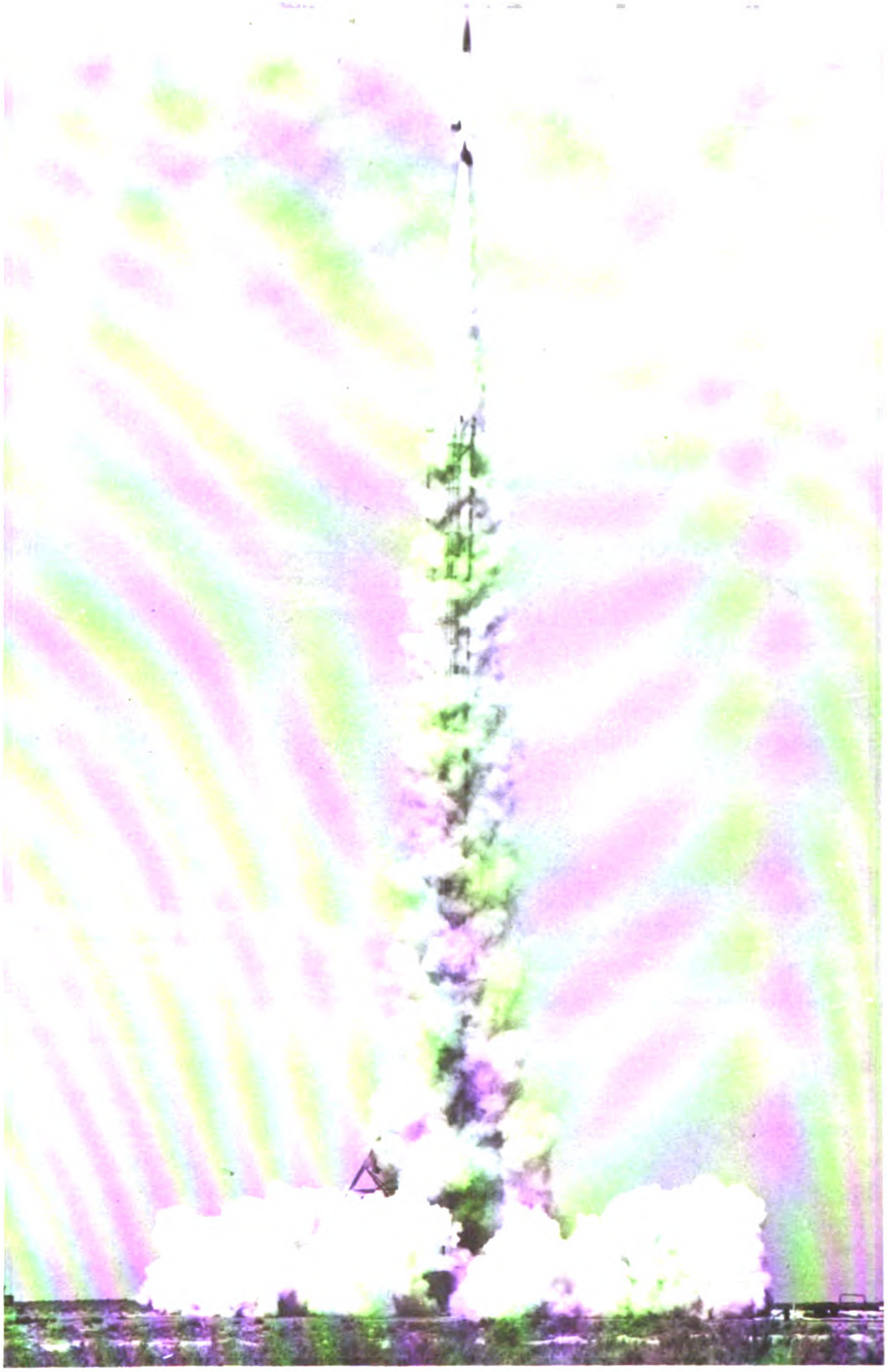


FIGURE 6. Launching of Aerojet X–8 "Aerobee" guided missile at Holloman Air Force Base, New Mexico.

to a maximum height of 240 miles. With this payload, the missile weighed only 9,500 pounds.

Much of the high-altitude research conducted at White Sands Proving Ground after World War II was carried out by about 100 of the top German scientists of the Peenemunde group who had been brought to this country for further work in guided missile research and development following the surrender of Germany. Some 5 years after the war, these scientists were transferred to Redstone Arsenal, Ala., the center of missile and rocket research and development for the Army Ordnance Corps. The program here was greatly accelerated in late 1954 with the establishment of the Army Ballistic Missile Agency. It was this organization that succeeded in placing the first American satellite in orbit on January 31, 1958, using a Jupiter C Intermediate Range Ballistic Missile as the first stage. The Russians, who had exploited German rocket equipment and personnel at the close of the war, had made sufficient advances in missile development to put the first artificial satellite, Sputnik I, in orbit on October 4, 1957.

The USAF, meanwhile, had been actively interested in ballistic missiles since the closing days of World War II, beginning with our knowledge of the German V–2. In 1946, the Air Force began an orderly and systematic missile development program. Contracts were negotiated for rocket propulsion and long-range missile development, as well as for study of missile guidance and control problems. In early 1951, a contract was awarded to Convair for the development of an ICBM; this was the original Atlas program. With the hydrogen nuclear breakthrough in 1953, which pointed the way to small, high-yield warheads, this program was greatly expanded and accelerated. In July 1954, the Western Development Division, now the Air Force Ballistic Missile Division (AFBMD), was established under Air Research and Development Command to manage Atlas research, development, and testing. The program was given highest Air Force research and development priority. In May 1955, development of the Titan ICBM was assigned to AFBMD; and, in the following December, Thor IRBM development was assigned to the Division. The ICBM programs now had the highest national priority. By March 1956, the Air Force, under the added responsibility for initial operational capability of both the ICBM and the IRBM, was proceeding with plans for constructing bases, producing operational missiles and supporting equipment, and activating, equipping and training missile units. In December 1957, the Thor made the first U.S. IRBM fully guided flight; and also in that month, the ICBM Atlas was successfully fired with all test objectives achieved.

TYPES OF MISSILES

There are so many variations of missile types that it has become difficult to categorize them properly. The proliferation of types within a relatively short time has led to a confusion of terms among the uninitiated. Newspapers and periodicals freely used terms such as guided missiles, ballistic missiles, pilotless bombers, guided bombers, or rockets, indiscriminately.

During the transition period from aircraft to aerospace weapon systems, various methods of classification have been employed by the armed services as a means of identifying missiles. The USAF originally thought of missiles as guided, or pilotless aircraft, and assigned the designation P/A to what are now known as guided missiles. The P/A were further subclassified according to their general purpose in relation to which type of manned aircraft might have similar roles. The Matador, for example, was first known as B–61 and the Bomarc as F–99, since their missions resembled those of bombers and fighters, respectively.

With the advent of the larger missiles, the term "ballistic missile" became popular. As previously noted, the term is technically incorrect in its application to any missile which employs any means of guidance after launching. However, popular usage has dictated acceptance of the term "ballistic missile" for those missiles which utilize some form of guidance during the initial flight, but which are affected only by natural forces (gravity or atmospheric hindrance) after the initial propulsive force has ceased to operate. Similarly, the term "guided missile" has been applied generically to all missiles which utilize some form of guidance control during the terminal portion of the flight, although not necessarily at the start. Some weapons, notably air-to-air rockets, fail to conform to either of these distinctions in that they have no control systems whatever (e.g., the USAF Genie rocket). Officially, the Air Force does not recognize a difference in missiles by presence or absence of guidance control systems, but has evolved its own system which classified its missiles by mission (e.g., Strategic Missiles, Tactical Missiles, etc.). The widely used and accepted abbreviations ICBM, IRBM, AICBM, and ALBM, are descriptive of type and capability, but are not official designations.

Classification of Missiles

A distinction must be made between missile types and missile designations. Even as aircraft are typed by general characteristic grouping, such as amphibian, monoplane, twin-engined, and the like, the missile families have been given a simplified family grouping code. Missile types are code-designated by a combination of three letters. The first and second letters denote origin and destination—A for Air, S for Surface, and U for Underwater—and the third, M, is for Missile. Thus missiles are typed as follows:

SSM—surface-to-surface missile
SAM—surface-to-air missile
SUM—surface-to-underwater missile
ASM—air-to-surface missile
AAM—air-to-air missile
AUM—air-to-underwater missile
USM—underwater-to-surface missile
UAM—underwater-to-air missile

In November 1954, Headquarters USAF provided for a further classification of missiles. Air Force missiles used for the tactical or theater air missions were designated as TM's. For example, the TM–61A Matador SSM is a tactical

missile. Missiles used for the strategic mission were designated as SM's; for example, the SM–62 Snark SSM. Air defense missile squadrons using interceptor missiles identify them with the letters IM. The IM–99 Bomarc SAM is an interceptor missile.

A true aerospace weapon is the intercontinental ballistic missile (ICBM), such as the Atlas and the Titan, which has a minimum range of 5,000 or 5,500 miles. A ballistic missile with a range from 200 to 1,500 miles, such as the Thor, is known as an intermediate range ballistic missile (IRBM). Ballistic missiles launched from aircraft are grouped under the general designation air-launched ballistic missiles (ALBM). For defense against the ballistic missile, another type of missile being developed by the Air Force is known as an anti-intercontinental-ballistic missile (AICBM). The Air Force has a number of developments in the field, some of which show promise.

Rockets are used either to supplement or entirely replace present armament on fighter or interceptor aircraft. Some of these rockets are guided only to the extent that, when fired, they go in the direction in which the aircraft is pointed. However, a true guided aircraft rocket must use some type of homing equipment which will enable the missile to seek out and destroy its objective automatically after the missile is launched toward the target area. Since such a missile is also an augmentation of armament, we use the letters GAR for guided aircraft rocket. An example is the GAR–1 Falcon AAM. Another type is a guided aircraft missile, or GAM. An example of this type is the GAM–63 Rascal ASM. The GAR is used against air targets, and the GAM is used against ground targets. We have, then, a variety of missiles for a variety of purposes, a fact which indicates the broad extent of this field.

Guided Missiles

Four of the five main classifications of Air Force missiles are considered guided missiles: GAR, GAM, IM, and TM. Specific examples of each will be found in Appendix B of this book.

GUIDED AIRCRAFT ROCKETS (GAR).—The increased complexity of the air-defense problem has imposed some peculiar demands on the guided missile designer in that the anticipated progress of a prospective enemy requires rather advanced interceptor weapon systems. However, envisioned interceptor devices have such long development lead times that some interim measures must also be employed. Consequently, a concurrent effort has been made to increase the armament capability of existing manned aircraft.

The evolution of aircraft rockets brought about an entire series of GAR missiles, differing mostly in the type of guidance system used. Homing is the most logical choice for guidance since the interceptor can bring the missile within a few miles of the target and, having solved the fire-control problem, launch the missile at the proper time. The missile guidance system is then left with the problem of making minor course corrections and compensating for evasive target maneuvers. A computer within the missile continuously determines the proper intercept course. Because of the homing system's inherent

FIGURE 7. Sentinels of freedom standing at attention are the new GAR–11 Nuclear Falcon, left, the U.S. Air Force's first guided air-to-air missile with a nuclear capability, with its brothers (from left) the radar-guided GAR–1D, the infrared guided GAR–2A, and GAR–3 Super Falcon.

ability to increase in accuracy as the intercept point is approached, the kill probability is quite high. If radar homing is used, it is usually of the semi-active type (transmitter in interceptor, receiver in missiles). This involves a considerable weight and space saving in the GAR. In addition, the interceptor, having already used its fire-control radar, is not significantly more vulnerable to detection by the target. GAR missiles using infrared (heat-seeking) homing guidance have been successfully used singly and in combination with radar types. While generally limited to the tailcone sector launch, the IR (Interrogator-Responser) GAR has the advantage of being passive (no transmitter needed). At the same time, it has advantages over the radar GAR's at low altitude. Until some form of passive fire-control system is developed, the weapon system must be considered active and subject to detection because of fire-control system radar emanations.

The best known GAR is the Falcon (Fig. 7). Falcon is actually the name of a family of air-to-air missiles used by fighters of the Air Defense Command. The GAR–1D and GAR–2A, the smallest missiles in the USAF inventory, have been operational since 1956 and are used on the F–89, F–101, and the F–106 aircraft. The GAR–1D is radar-guided, while the GAR–2A has an infrared device. GAR–3 and GAR–4 are improved versions of the earlier models. GAR–9 was programmed to combine the accurate guidance system of the earlier Falcons with the nuclear capability of the unguided Genie. Most GAR's can be carried in mixed loads, e.g., both radar-guided and heat-seeker types can be carried on the same aircraft.

Guided Aircraft Missiles (GAM).—Previously, strategic weapon systems have involved flying manned bombers in over a target at an altitude consistent with the accuracy of the bomb navigation system in use. During the period of the "bomb run" the aircraft is generally unable to employ evasive maneuvers and, therefore, quite vulnerable to anti-aircraft fire. Projecting enemy weapons progress along a line with our own would indicate that future bombing missions will encounter more accurate AA fire and interceptor-type missiles. The GAM offers some solution to this problem. Carried by a conventional bomber, the GAM can be launched far in advance of the target and well outside the inner perimeter of defense. The GAM will then fly to its operational altitude and proceed toward the target guided either internally or from the parent aircraft. With a multi-mach, high altitude capability, the GAM will be difficult to counter. The combination of a GAM and a more sophisticated supersonic bomber, such as the B–58, results in a highly effective strategic weapon system.

While the GAM usually follows the pattern of the strategic device just described, any air-launched missile with a ground target falls in this category. Small decoy missiles equipped with radar and IR reflectors to simulate larger aircraft can be carried by bombers and launched prior to reaching the target area. This tactic could easily compound the enemy's air defense problem as the decoys would appear as full-sized bombers to radar and IR detectors. Having expended their fuel, the decoys would fall in the target area and, if armed with a small warhead, might inflict some superficial damage. Decoys, employed properly, could effect an early launch of enemy interceptors and/or

interceptor missiles. Follow-up penetration, during interceptor turnaround or after enemy IM expenditure, would have a much greater probability of success.

The two best known GAM's are both considered ASM's, but have entirely different missions. They are the GAM–77 Hound Dog and GAM–72 Quail. The Hound Dog, with nuclear warhead, a J–57 or J–52 turbojet engine, and a range of over 500 miles, can extend the effective range of a Strategic Air Command bomber, and at the same time offer maximum safety for the crew of the launch aircraft. It has the added advantage of being supersonic. The Quail is a diversionary missile, i.e., it is launched from B–47 or B–52 bombers as a decoy. Its purpose is to assist in target penetration by diverting enemy attention. On a radar screen it's "blip" has the same characteristics as a heavy bomber.

INTERCEPTOR MISSILES (IM).—Interceptor missiles are designed to complement other air defense weapons in both point and area defense. As outlined in the now famous Wilson Memo (November 1956), area defense involves interception "remote from and without reference to individual vital installations, industrial complexes or population centers . . . . Point defense has as its purpose the defense of specified geographical areas, cities and vital installations." Area defense missiles will receive their guidance information from the major air defense network whereas point defense missiles will be guided by local tracking and acquisition radars. In most cases guidance will be a combination of command and homing. (These systems are described in Chapter 10.)

IM's must be designed for a long standby period in the ready state and for a minimum launch time. While possessing the obvious advantage of having no turnaround time, the IM, blinded by its homing system's inability to differentiate targets, is susceptible to diversionary measures by decoy missiles.

The only surface-to-air missiles actually designated IM are the Bomarcs. Army and Navy missiles of this type bear only the SAM designation (e.g., SAM–A–25 Nike-Hercules and SAM–N–7 Terrier). As indicated above, the IM–99 Bomarc is often referred to as a pilotless fighter or pilotless interceptor. The Bomarc–A, with two ramjet engines and an aerojet liquid fuel booster, has a range of about 250 miles; the Bomarc–B, with a Thiokol solid propellant booster, has a range of about 400 miles. The Bomarcs are an integral part of the SAGE system and have been successfully controlled from 1,500 miles away. They have a ceiling of over 60,000 feet, supersonic speed, and may be armed either with high explosive or nuclear warheads. Army and Navy SAM's are designed for point defense; the Bomarc for area defense.

TACTICAL MISSILES (TM) AND STRATEGIC MISSILES CRUISE (SM CRUISE).—The Tactical Missile is a replacement for the fighter-bomber's close support capability. The Strategic Missile Cruise is a much longer range weapon system with a strategic objective. The "cruise" qualification is made to distinguish this type which has a propelled mid-course phase from the purely ballistic SM to be discussed below. Aside from the propulsion system, which must operate with a reasonably high thrust over the entire range (about 600 miles for the TM and as much as 6,000 for the SM Cruise), the main problem is one of

guidance. Since the target is not visible from the launching site, some form of preset guidance (inertial, celestial, etc.) must be used. Command guidance could be used in the case of the shorter range TM if a chase plane were used. This method has many disadvantages. The TM weapon system must be extremely mobile—with a guidance system flexibility sufficient to handle the variety of target situations encountered. The versatility of the TM could greatly increase our capability for low-level reconnaissance missions. The SM, despite its complex systems and service procedures, must be ready for immediate launch and available in sufficient quantities for a sustained high firing rate.

The first operational tactical missile was the Matador, which made its first flight in 1950 as a "pilotless bomber." The Matador (TM–61) required guidance by ground personnel, but its second-generation replacement, the Mace (TM–76) has either an inertial guidance system (TM–76B) or ATRAN, a map-matching system (TM–76A). The best known Navy tactical missile is the SSM–N–8 Regulus. The Army has a number of well-known tactical missiles in operational use, including the Corporal, Sergeant, and Lacrosse. While the range of the two Air Force TM's are between 200 and 400 miles, and the Navy's Regulus approximately 500 miles, the Army TM's are considerably shorter in their operational radius. Pershing has the greatest radius, approximately 350 miles.

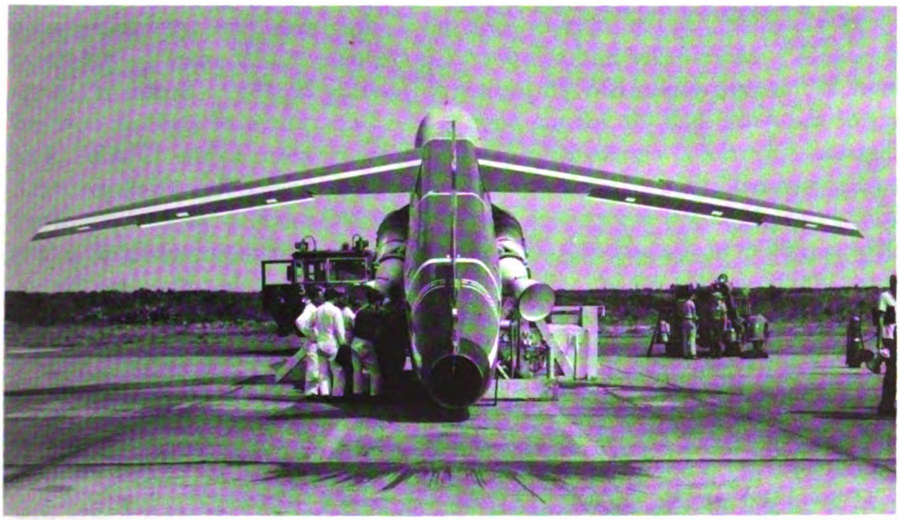


FIGURE 8. Technicians prepare to fire the U.S. Air Force SM–62 "Snark" missile. The 69-foot missile can deliver a nuclear warhead to a range over 5,000 miles, flying at near-sonic speeds at altitudes above 35,000 feet.

The SM–62 Snark, America's first intercontinental missile, is of the "cruise" classification. A "pilotless bomber" type, the Snark can travel 5,000 nautical miles at near-sonic speed, with either an inertial guidance system, or under control. In a test of its response to controlled direction, the Snark has been fired

some 1,300 miles and, fitted with retractable landing gear, has turned around to return and land at its launching site. Under these conditions, it could be considered the only intercontinental range missile with recall capability.

Ballistic Missiles

Although the Air Force initiated intercontinental ballistic missile development immediately after World War II, a militarily attractive ICBM did not become technically feasible until after the hydrogen nuclear bomb development in October 1952. Scientific appraisals of the significance of the hydrogen warhead to the program were performed independently by the USAF Strategic Missiles Evaluation Committee (SMEC) and the Air Force-sponsored RAND Corporation. Both submitted their recommendations in February 1954, and as a result, the Air Force moved rapidly to give the Atlas program number one USAF priority.

Since those days, unprecedented technological strides have been made. Most interesting, perhaps, is the speed with which the ICBM's and IRBM's became operational. In July 1954 the USAF established the Western Development Division (now Air Force Ballistic Missile Division, Inglewood, Calif.) to direct the ballistic missile development program. In December 1955 the responsibility for the development of the Thor was assigned to BMD, and less than 2 years later the first SM–75 Thor was launched successfully from Cape Canaveral. Similar speed was evident in the other ballistic missile programs. The Army launched a Jupiter A in March 1956 and a Jupiter C in September 1956; and the Air Force launched an operational SM–78 Jupiter on January 22, 1959. (Begun as a project of the Army Ballistic Missile Agency, the Department of Defense directed that the operational employment of the Jupiter be given to the USAF.) The best known ballistic missile, the SM–65 Atlas, made its first flight in June 1957, and in early 1960 was pronounced operational with an average inaccuracy of less than two miles at the end of 5,000-mile flights. It has made successful flights of considerably greater range, and has been used for a number of space flights. Shortly after it became operational it was announced that the Atlas-E had made the first successful all-inertial guidance flight of any ICBM.

The Atlas, Jupiter, Thor, and Titan are all propelled by engines employing liquid fuels. The immediate disadvantage of such propellent systems lies in the time element: after a signal to launch has been given, valuable time is lost in the ensuing "count-down" before the vehicle can actually rise from its launch pad. A second disadvantage which could conceivably be fatal is the fact that the first three (or first generation) of these ICBM's did not lend themselves to a "hard" site, but would be vulnerable to attack at all times. The Titan was developed with this specific requirement: that it incorporate certain advanced design features which would allow it to be launched from underground "silos" which were built-in features of the "hardened" launch sites. The "hardness" of a launch site is an expression of the resistance it can offer to an enemy nuclear weapon attack. Conversely, the more vulnerable the launch site, the "softer" it is said to be.

None of the early liquid propellent missiles are satisfactory for the popular concept of "push-button" warfare since they lack stability of fuel and require considerable human attention in their preparations for launching. Other disadvantages are the lack of mobility, large size, and high cost of production. Continued research, utilizing lessons learned in the use of the liquid-propellent ICBM's and IRBM's, resulted in the production of the SM–80 Minuteman.

Mobility, hardening, quicker firing, lighter weight, smaller size, and lower cost make the Minuteman almost a different weapon compared to the other, first-generation, ballistic missiles. The three-stage solid-fueled Minuteman was developed to be scattered throughout the United States in hardened underground silos or mounted on mobile railroad cars traveling over the nation's vast railway system. Its solid fuel also permits it to be loaded and ready to be launched in seconds if necessary, since the entire countdown can be completed in advance, leaving only the actual firing to be actuated on signal. Even the firing signal can be given by remote control.

The United States Navy developed the Polaris missile with characteristics similar to the Minuteman. Designated an FBM (Fleet Ballistic Missile), the Polaris is a solid-fueled, two-stage IRBM which can be fired from land, surface vessels, or specially designed submarines. In the latter instance, missiles are carried aboard the submarines in individual containers and at launch time are propelled above the surface by inert gases and then fired. Advanced versions of this extremely versatile missile have a range of 1,500 miles (compared to the Minuteman's range of 5,500 miles).

TRAJECTORIES

A trajectory, in its original meaning, may be defined as the curve traced in a vertical plane by a bullet, shell, bomb, or other object thrown, launched, or trajected by an applied exterior force, the projectile continuing in motion after separation from the force. This meaning has been extended to include the path traced in a vertical plane by a winged guided missile, a rocket, or a ballistic missile, such missile being propelled by fuel either the whole distance or a part of it. This extension of meaning has rendered the word "trajectory" ambiguous. The word no longer clearly differentiates between the entire path traced, and that part of it during which the missile is no longer under propulsive force. Since a term descriptive of the last is required, the term "ballistic trajectory" has been introduced.

Ballistic missiles follow a ballistic trajectory only after cutoff of the initial power which gives them velocity. During the power phase, guidance of various types is applied. Despite the guidance influence exerted in this stage, it is distinguished from guided missiles because of the ballistic trajectory which characterizes most of its journey. The term "ballistic missile" has a strong connotation of a missile designed to travel outside, or in the outer reaches of the atmosphere before plunging toward its target.

Factors Affecting Missile Trajectories

The principal factor affecting a missile's trajectory is, of course, the design of the missile and its guidance system. This section will deal only with other external forces affecting the trajectory. Such factors include wind, gravity, magnetic forces, and the coriolis effect. In the use of any long range missile, all of these must be taken into account.

All missiles fly through the atmosphere, either during their entire flight or at the beginning and end of it. They are therefore liable to be pushed off the desired course by the force of the wind. The magnitude and direction of the prevailing winds at various points on the earth are well known. But the prevailing winds are much modified by a number of factors such as local topography, thermal updrafts due to local heating of the earth's surface, the distribution of high-pressure and low-pressure air masses, and storms and their associated turbulence. All of these factors can be predicted to some extent, but the reliability of the prediction decreases with both time and distance. For that reason, air-breathing missiles must be provided with means for correcting any deviation in course that might result from unpredicted winds. A ballistic missile may be subject to correction as it rises through the atmosphere. But it descends on its target at such a speed that the effect of wind is unlikely to produce a serious error.

A long range missile using a navigational guidance system may use the direction of the center of the earth as a reference. It does so by using a pendulum,

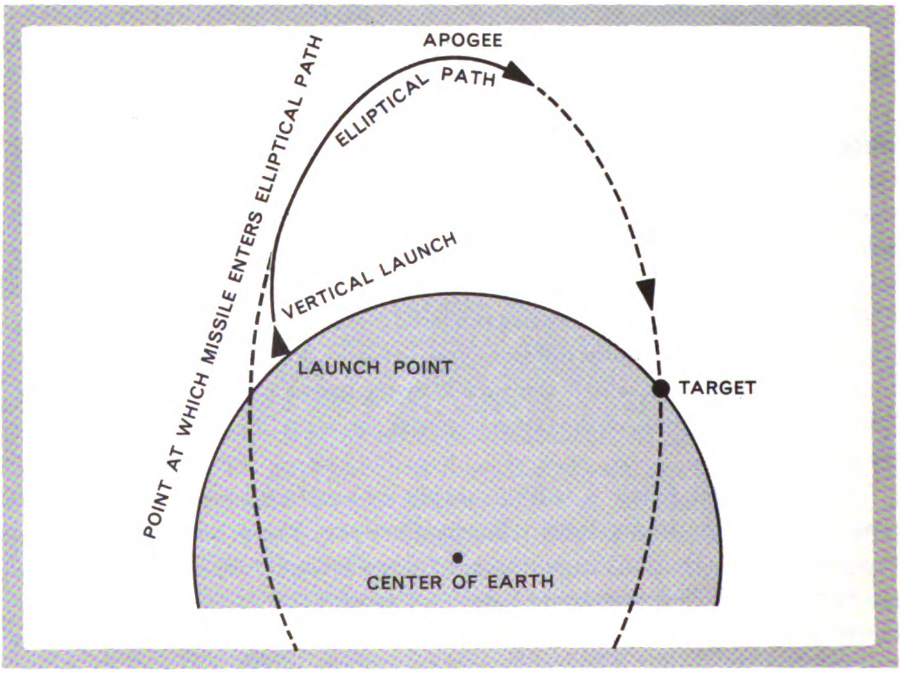


FIGURE 9. Ballistic missile trajectory.

plumb bob, or some similar device, to measure the direction of the gravitational force. But the measuring device is acted on by two forces: gravity, which tends to pull it toward the center of the earth; and centrifugal force, caused by the earth's rotation, acting at a right angle to the earth's axis (Fig. 9). The direction indicated by the measuring device is that of apparent gravity—the resultant of the two forces. The motion of the missile itself will create additional forces that tend to disturb the gravity-measuring device. Any missile guidance system that uses a gravitation reference must compensate for these disturbing forces.

Some missiles may use the strength or the direction of the earth's magnetic field as a reference for navigation. But both strength and direction of the field vary from point to point on the earth. In general, these variations have been measured and plotted. But at any given point on the earth, the magnetic field is subject to annual, monthly, and even daily variations. It is subject to non-periodic variations in "magnetic storms" that result from bursts of ions or electrons radiated from the sun. Most of these variations are predictable with reasonable accuracy, and can be taken into account in the missile guidance system.

The coriolis force must also be compensated for. It is caused by the earth's rotation, and tends to deflect a missile to the right in the Northern Hemisphere, and to the left in the Southern Hemisphere. As the earth turns on its axis, its surface moves toward the east at a rate determined by latitude. At the equator the earth's surface is moving to the east with a speed of more than 1,000 mph; at the poles, its speed is zero.

Assume that a missile is launched directly northward in the Northern Hemisphere. At the instant of launching, it will be moving to the east at the same rate as the surface from which it is launched. But as it moves northward, it flies over points whose eastward velocity is less than its own. As a result it will be deflected eastward, or toward the right. Now imagine a missile fired southward in the Northern Hemisphere. It will fly over points whose eastward velocity is greater than its own. It will therefore be deflected westward (still to the right) with respect to the surface.

The amount of deviation produced by the coriolis force depends on the latitude, length, and direction of the missile flight. Since it can be accurately predicted, suitable corrections can be made by the missile guidance system.

Guided Missile Trajectories

Missile trajectories include many types of curves. The exact nature of the curve is determined by the type of guidance and the nature of the control system used. For some missiles, the desired trajectory is chosen before the missile is designed, and the missile is closely limited to that trajectory. Other missiles, such as Regulus, may offer a choice of trajectories.

HYPERBOLIC SYSTEM.—A missile using a hyperbolic guidance system will first climb to the desired altitude, then follow an arc of a hyperbola before diving on its target. If the control stations are ideally located with respect to

the target, the hyperbolic course is a close approach to a straight line. This system is described in a later chapter.

PURSUIT CURVE.—Some homing missiles, and some beam riders, follow a pursuit curve. At any given instant, the course of the missile is directly toward the target. If missile and target are approaching head-on, or if the missile is engaged in a tail chase, the pursuit curve may be a straight line unless the target changes course. But a missile that pursues a crossing target must follow a curved trajectory. As the missile approaches a crossing target, the target bearing rate increases, and the curvature of the missile course increases correspondingly. In some cases the extreme curvature of the pursuit course may be too sharp for the missile to follow.

LEAD ANGLE COURSE.—Some homing missiles follow a modified pursuit course. The deflection of the missile control surfaces is made proportional to the target bearing rate. The missile flies not toward the target, but toward a point in front of it. The missile thus develops a lead angle, and the curvature of its course is decreased.

A further refinement is possible if a computer, either in the missile or at a control station, can use known information about the missile and target to calculate a point of intercept which missile and target will reach at the same instant. Because the missile is guided directly toward the point of intercept, its trajectory is a straight line. If the target changes course during the missile flight, a new point of intercept will be calculated, and the missile course will be turned toward the new point of intercept.

BEAM-RIDER TRAJECTORY.—A beam-rider missile may follow either a pursuit curve or a lead-angle course, depending on the type of system used.

FLAT TRAJECTORY.—An intermediate-range or long range air-breathing missile is usually made to climb as quickly as possible to the altitude at which its propulsion plant operates most efficiently—somewhere between 30,000 and 90,000 feet. After reaching this altitude the missile flies a flat trajectory to the target area. Regulus, for example, can be made to climb steeply to a desired altitude, level off, fly a flat trajectory to the target area, then dive straight down.

Ballistic Missile Trajectories

Figure 10 illustrates a probable trajectory for a long range ballistic missile. The missile is launched vertically, so that it can get through the densest part of the atmosphere as soon as possible. At a certain altitude which may be controlled by either preset or command guidance, the missile turns to a more gradual climb. After burnout, or shutdown, of the propulsion system by radio command, the missile "coasts" along a ballistic trajectory to the target.

Three phases characterize the flight of a ballistic missile: the powered phase (from the initial launch to the thrust cutoff point), the free-fall, or free-flight, phase (during which it reacts to ballistic forces, describing a giant elliptical course as it curves back toward the earth), and the re-entry phase (when the missile penetrates the atmosphere for its final approach to the target). During

the last phase its path is a ballistic path, as during the second phase, but subject to the additional influences of ever denser atmosphere as it plunges downward.

The nose cone of a ballistic missile may be compared to an extremely long range artillery projectile carrying a high-explosive, nuclear, or thermonuclear device. Like an artillery shell, it follows an elliptical trajectory. Since the artillery shell cannot be controlled in flight, the total amount of control that the artilleryman has over the trajectory of the shell is determined within the gun—by the amount of explosive charge and by aiming the barrel.

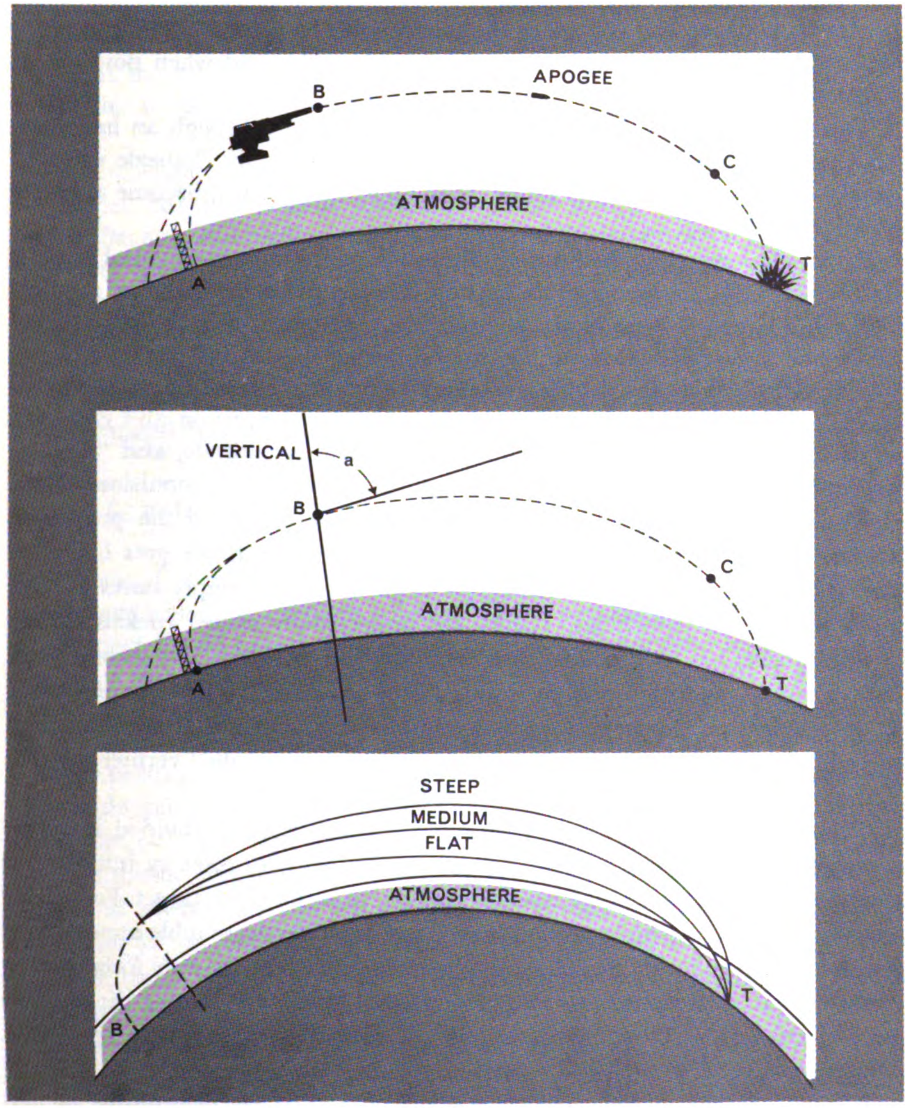


FIGURE 10. Types of trajectories.

Suppose for a moment that we have such a gun, capable of firing a shell over 5,000 miles, and that we place it at a point B in space. We make our calculations of muzzle velocity, range, direction and so on, and fire the shell. We know it will follow a trajectory up into space, and then down onto the target.

The problem, of course, is that we have no such gun, and could not station it at point B if we had it. So it is the job of the ballistic missile designer to produce a missile which can be launched from point A on the ground, and guided with such accuracy that it will leave point B at the proper velocity and pointed in the right direction. Power is applied to a ballistic missile only during the initial portion of its flight, that is, from A, the launch point, to B, the thrust cutoff. All necessary guidance and control of the missile must be accomplished during the powered flight, for the missile motion cannot be influenced when power is no longer available.

This task is equivalent, then, to guiding the projectile through an imaginary (but correctly aimed) gun barrel at point B, at exactly the "muzzle velocity" required to give it the correct range. How difficult this is will become apparent as we proceed.

Extremely long range ballistic missiles, such as the intercontinental ballistic missile (ICBM), are launched straight up. This simplifies the launcher required for such a large vehicle and also shortens the time that it is in the dense drag-producing atmosphere close to the ground during the takeoff phase. After its initial vertical climb, the vehicle makes a planned turn toward the thrust cutoff point. During this turn, the guidance system begins to function and continues to do so until the missile reaches the required velocity, altitude, and "aiming" angle. At this point (point B), it automatically cuts off the propulsion system.

The power requirements for an ICBM are quite large and the propulsion systems constitute a considerable weight. Of course, the missile gets lighter as fuel is consumed, but it is advantageous to get rid of the empty tanks as well. As with satellite launchings, ICBM are projected by staged rockets. When the first rocket has used its fuel, it is detached and dropped. The second stage is then started, and it propels the missile on toward B. As the missile approaches B, the engines on the second stage are shutdown, and the final adjustment of direction and velocity is accomplished with small rockets, called vernier engines. These, finally, are shut down just as the missile passes B.

The trajectory beyond the thrust cutoff point B may be divided into two segments: the free-flight portion, from B to the point of re-entry into the atmosphere (point C); and the re-entry portion, from C to the target. For a long range missile the free-flight portion from B to C is above the sensible atmosphere; hence the missile during this phase is a freely falling body, the only forces acting on it being its own momentum and gravitational attraction. During the re-entry portion from C to T, aerodynamic forces—primarily friction—also come into play, and these slow the missile and cause it to become heated.

The length and shape of the free-flight trajectory are determined by the speed of the missile at thrust cutoff, the angle between the local vertical at B

and the missile's direction of travel (angle a), the altitude of point B, and the values of the downward acceleration due to gravity along the trajectory.

There are many sets of values for velocity, angle, and the special position of point B that will put the missile on a trajectory to the target, but some sets are more desirable than others in respect to the amount of propellant required or the precision of aim.

Considering a given point B and a given target T, one finds that for every thrust cutoff speed between the lowest and the highest values needed to reach the target, there are two values of the climb angle at B that yield trajectories connecting B and T. One of these trajectories is steep, of high apogee; the other is flat, of low apogee. If we try lower and lower thrust cutoff speeds, we find that the two possible trajectories for each speed begin to approach each other, the steeper trajectory becoming flatter, and the flatter trajectory more arched.

Finally, when we use the minimum cutoff speed at which the missile will reach the target, the two possible trajectories merge into a single one of medium height. Because this medium trajectory requires the lowest cutoff speed, it is the trajectory that requires the least fuel to establish. The medium trajectory is also more favorable in other respects. For a steep trajectory the re-entry speed is high, thus presenting a more formidable heating problem. For a flat trajectory, the re-entry path through the atmosphere is long.

As can be seen, the determination of the correct trajectory for such long flights is complicated by many factors.

LOGISTICAL SUPPORT OF BALLISTIC MISSILES

Contained within any missile is a collection of electronic and mechanical equipment which must replace a fighter pilot or perhaps a whole bombing crew. If any part should fail, there is no one present to compensate for or repair the failure as in a piloted aircraft. Every part must function properly if the missile is expected to complete its mission. To reduce the possibility of failure during flight, all equipment is thoroughly checked before flight.

Final prediction of missile performance depends on checkout procedures, and the checks must be designed to be as reliable and complete as possible. To be so, they must be performed correctly and in the proper order. The manufacturer supplies missile checkout procedures to guide personnel on what to do, how to do it, and when to do it in order to insure that the missile will be prepared for launching at the required time. It is often necessary to coordinate with other checkout teams who must work on the missile previous to, during, or after a particular check.

Speed and accuracy in preflighting a missile are most important objectives. The time lapse between the decision to fire and the actual launching must be an absolute minimum because military tactics and strategy demand that the preparation for firing be short (Fig. 11). For this reason each check is designed

to be as brief and simple as possible, considering the nature of the tests. An assembly line procedure and a strict time schedule are normally used. In most cases a maximum amount of work, such as component testing, has already been done in storage and assembly areas and at the place of manufacture.

An assembly area may be located many miles from the actual launching area. A missile of the SSM or ASM type may vary greatly in size and configuration.

The airframe of a particular missile may be broken down into nose section, center section, and propulsion section. Prior to assembly of these components, the major sections can be easily approached for power system checkout, guidance system checkout, controls checkout, and propulsion checkout. Different teams will be assigned for each project.

Thus many types of mechanical and electronic components can easily be installed and checked for operation. The checks will be detailed and time consuming. If certain items are not available during assembly, they must be secured. A final check is made, and the missile must be complete as a unit before it is put in storage. A certain number of such units must be constantly available to be sent directly to a launching area when needed. In some cases equipment necessary to transport the missile to the launching area must be specially designed.

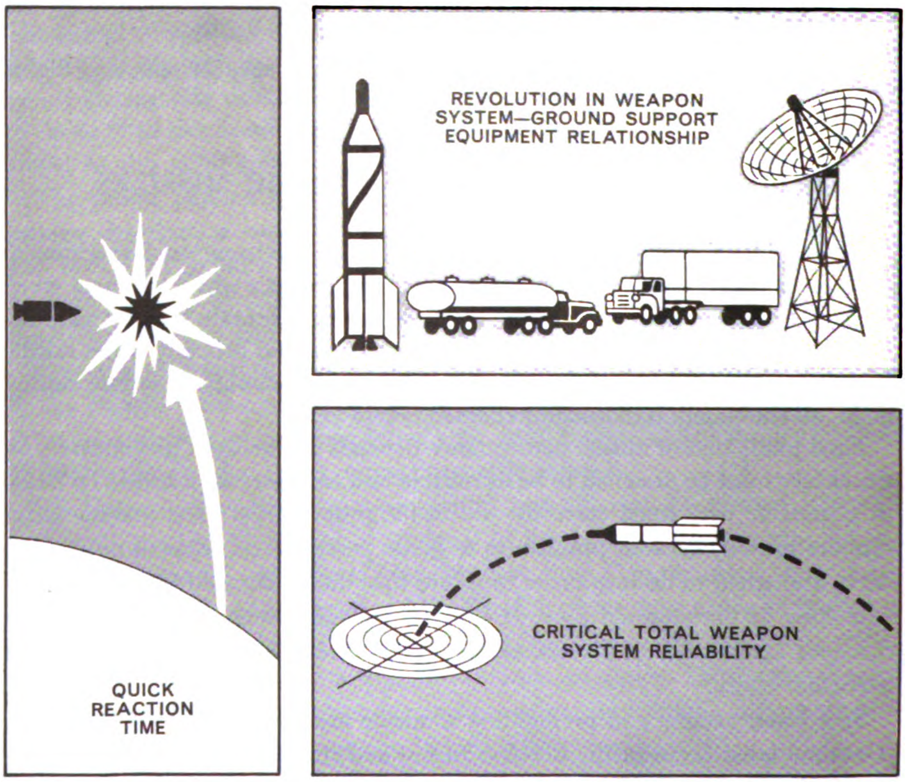


FIGURE 11. Problems facing the ballistic missile logistician.

In the event of a component's being inoperative at the time of installation, it will be sent to the maintenance section of the assembly area. A similar component to replace the defective unit must be available so that the assembly time schedule will not be interrupted. In the maintenance section, specialized personnel will attempt to repair all types of such units. After a repair is completed, the unit will be placed in supply and made available to assembly personnel.

The foregoing is but a generalized view of the immediate logistical support required for missiles. When one considers the tremendously complex mechanisms which must function perfectly to bring about a successful launch, it becomes obvious that a very high degree of efficiency must perforce be maintained in the logistical support systems upon which the missiles depend. To carry out the required backup in materiel a special logistics program was developed. It was no small endeavor to develop a logistical program for the support of the manned weapon systems: the mixed force, with its growing ratio of missiles, demanded a complete new support system.

A great depth of logistical planning and preparation is necessary to insure our ability to provide this kind of support. The Air Force has been working at it for several years, since some time before integration of the missile units into our forces. Logistic programs for the big ballistic missiles were under study and in preparation for some time.

It must be remembered that the ballistic missiles are totally new weapons. There was no operational experience with them to establish precedents, no statistics of usage to work from, other than experimental test results.

Two crucial considerations must be paramount in all planning: first, and of overriding importance, what will provide the most effective ready mission support for these weapons; what will best enable them to do the job for which they were created? Second, how can we best balance this against the economic limitation of available defense resources?

Another major task of the past few years has been the realignment of industrial resources for missile production.

American industry in general has played a most responsible role in the engineering and development of missiles. Whole new industrial segments specializing, for instance, in electronics and propulsion have come into being to meet our need. Missile requirements, altering the structure of Air Force procurement, have shifted emphasis increasingly to the weapon systems approach, a sharper focusing of industrial responsibility for the complete working package.

Most notable, perhaps, in the creation of the industrial base for missile production has been the development of production and tooling techniques simultaneously with development of test missiles.

In this way, the item tested—once it is accepted—can be manufactured in quantity without fabrication delays. Missile components have been designed from the outset for producibility. Also, the necessary facilities for production have been brought into being at the same time as the component itself.

As the policies and industrial base of ballistic missile logistics have been

molded over the past few years, the Air Materiel Command had also been working to improve Air Force capabilities with the new techniques and tools essential to the speed and precision of ballistic missile support.

To insure complete logistical support in the shortest possible time, the Air Force has established an electronic control system which does in minutes a complex logistics job which previously had taken days. The Electronic Data Processing Center (EDPC) is the electronic watchdog over thousands of parts and assemblies, and the clearing house for all the logistics transactions needed to keep the operational forces in a constant state of readiness. A web of communications connects the missile squadrons with whichever source of assistance is needed: the AFLC Weapon System Storage Site, the contractor supply and maintenance facilities, or an AFLC depot. The electronic computers digest information data and feed orders out to the responsible agency, as well as trigger the airlift responses which will move the materiel.

Figure 12 illustrates a simplified outline of the electronic net serving the San Bernardino Air Materiel Area, which serves as the logistics support manager for the ICBM's Atlas and Titan, and the IRBM Thor. Similar nets exist for the AMA's supporting Jupiter, Minuteman, etc. In addition to their own particular communication nets, each of the AMA's are connected with all others through the over-all AFLC Communications Logistic Network (COMLOGNET). The using organization (e.g., the missile squadron), through the use of electronic data cards, feeds initial information into the system to reflect its need for spare parts, or maintenance assistance, or whatever the requirement happens to be. From that point on the EDPC takes over and makes the necessary connections to insure that the requirement is satisfied in the shortest possible time.

As items are shipped to the operational squadrons, a pre-punched electrical accounting card is sent with the item. When this item is used, the card with additional information punched into it at the operational squadron is dropped into the transceiver network and the information is automatically transmitted back to the Electronic Data Processing Center. From the information available in the memory of the EDPC, determination is made as to whether a replacement item should be shipped, and if so, where it is available. If an item is to be shipped, shipping instructions are transmitted to the facility storing the item, and the item itself is sent to the operational squadron. Supply and resupply is accomplished by the most expeditious means of transportation available, consistent with economy and time.

The system is too complex to permit detailed examination in this course. It reaches far beyond the mere supply and resupply of the operational squadrons, and affects the entire ballistic missile program, including the planning for procurement, actual procurement of weapons and spares, the programming of further production or cutback in production of parts, etc. The missile program is not only a mission of AFLC, but includes a mixture of skill and professional knowledge from representatives of other major air commands, such as SAC, ATC, AFSC, etc., and, of course, the many technical specialists of the participating contractors.

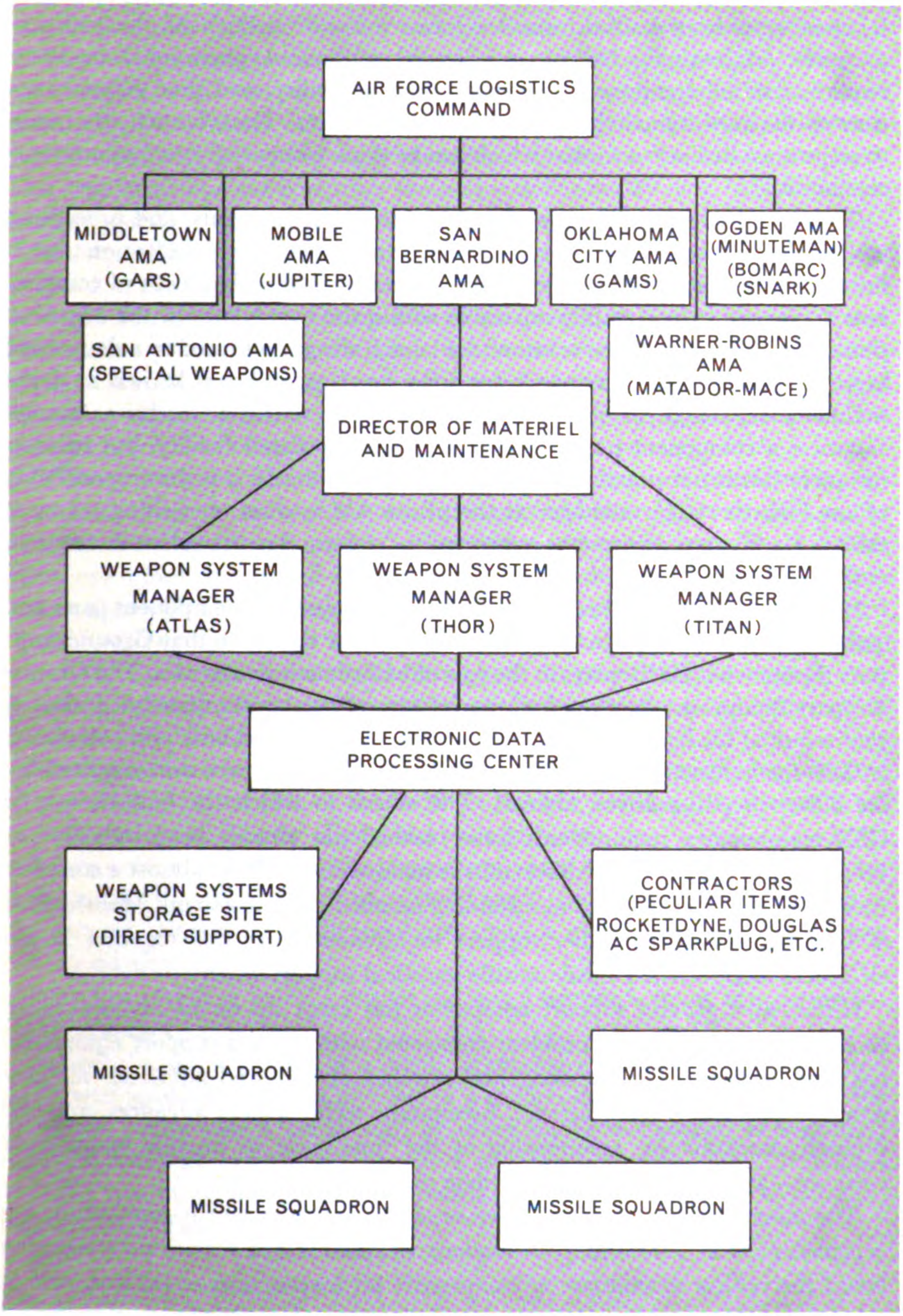


FIGURE 12. Missile Logistics Support Manager Program, as exemplified by SBAMA. Other AMA's have similar systems tailored to the demands of the weapons or weapon systems they support.

In addition to the procurement and supply of missile components, maintenance support of ballistic missiles forms a major portion of the logistical program. Maintaining ballistic missiles in continuous operational readiness requires that all components have optimum reliability, and that maintenance time at the operational sites be kept at a minimum. Thus, launch site maintenance must be limited to that which can be done without affecting operational capability.

To insure this capability, the design of systems, components, and procedures has been tailored to the concept of minimum maintenance and inspection time at the launch emplacement, and expeditious removal and replacement of components. Components not readily reparable within the capabilities of the organization or mobile maintenance teams at the launch site are returned to a designated overhaul activity. Maintenance beyond the local capability is known as depot maintenance, and is performed either by AMA or contractor facilities. In most instances a component part will be shipped to the depot facility, but in some instances this is not practical. To meet these latter needs, it is the responsibility of the logistics system manager at the prime AMA to set up visiting teams of skilled Air Force or contractor personnel to perform depot level work required at the launch site.

While most readers will readily conceive of the needs for component parts and maintenance on the missile itself, few will consider the place that Ground Support Equipment (GSE) plays in the role of ballistic missile logistics. The Ground Support Equipment required for manned aircraft is almost minor in contrast to that required for launching ballistic missiles. The increased bulk and complexity of GSE for modern jet aircraft increased a hundredfold over that required for the older, propeller-driven aircraft. The extent to which the ballistic missile GSE maintenance requirements have reached has already been indicated at 80 percent of the over-all ballistic missile maintenance effort: almost a complete reversal of the ratio required in sustaining manned aircraft systems. Maintenance of GSE, as well as the other support requirements, are tied together in the electronic heart of the ballistic missile logistical support system.

Historically, ground support equipment has crept up on us in importance each successive year. The problem connected with ground support equipment has been dynamic. Defense concepts, entrance of new and advanced military weapons into the defense arsenal, precipitant technological advances, and the dramatic necessity for compression of the time cycle to provide operational weapons—all have had vital effects upon such equipment.

The most significant change, however, is the extent to which automation has replaced man in relationship to modern weapons. Since man is no longer on board the vehicle to calibrate or compensate for inaccuracies or failures, and to take over manually where automation fails, the mission is directly dependent upon how well the supporting equipment functions.

When we think of the ground equipment necessary to support and operate ballistic missiles, we must now consider a much broader area than that for

past weapon systems. All of the mass of ground support equipment used in conjunction with ballistic missiles may be divided into two subcategories:

FIRST.—That equipment which functions as a part of the weapon, although not installed in the weapon. Examples of ground operating equipment (as we use it today) are launch control consoles, checkout and countdown equipment, ground conditioning systems, water pumping and distribution systems, et cetera. This type of equipment comprises the major dollar outlay on a ballistic missile weapon system.

SECOND.—That equipment used primarily in test, maintenance, calibration, servicing, repair, and transportation. The first subcategory is distinguished from the second in that it does not operate as an integral part of the weapon, and performs no part of the operational function of the weapon itself. However, when combined, ground support equipment amounts to almost 80 percent of the entire weapon system cost in some ballistic missile configurations as well as a similar percentage of maintenance effort.

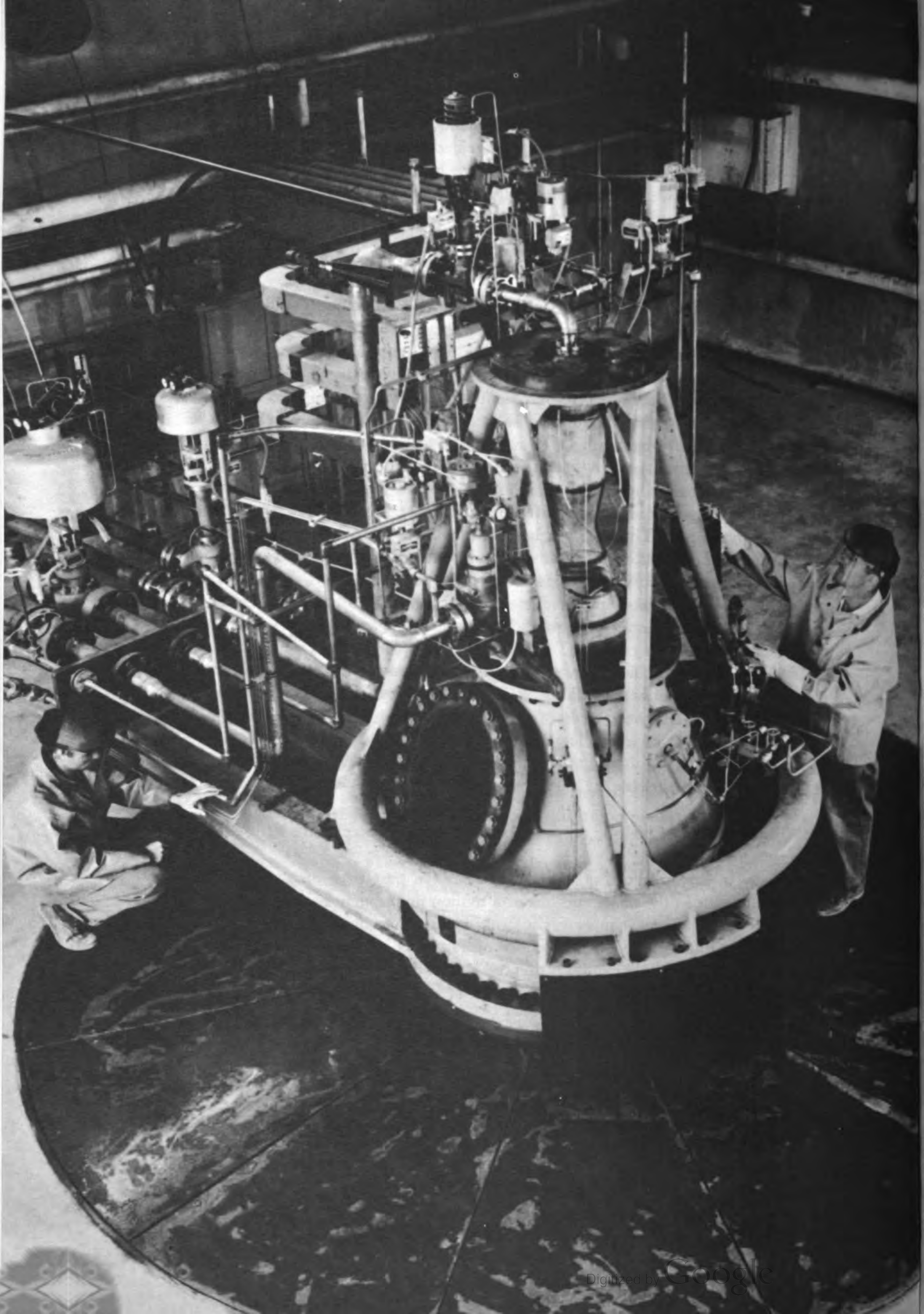
GSE—as we know it today—makes interesting comparison to related equipment used in recent military history. During World War II, when our combat force consisted mainly of manned aircraft, ground equipment played a comparatively minor part. The B–29 bomber, which was one of our mainstays in that era, used only 2 percent of the total weapon system dollars for ground support equipment. Furthermore, it was possible to start the B–29 on its own battery system. The pilot was in command throughout the mission of the aircraft, even though a large portion of the ground equipment might have been out of commission.

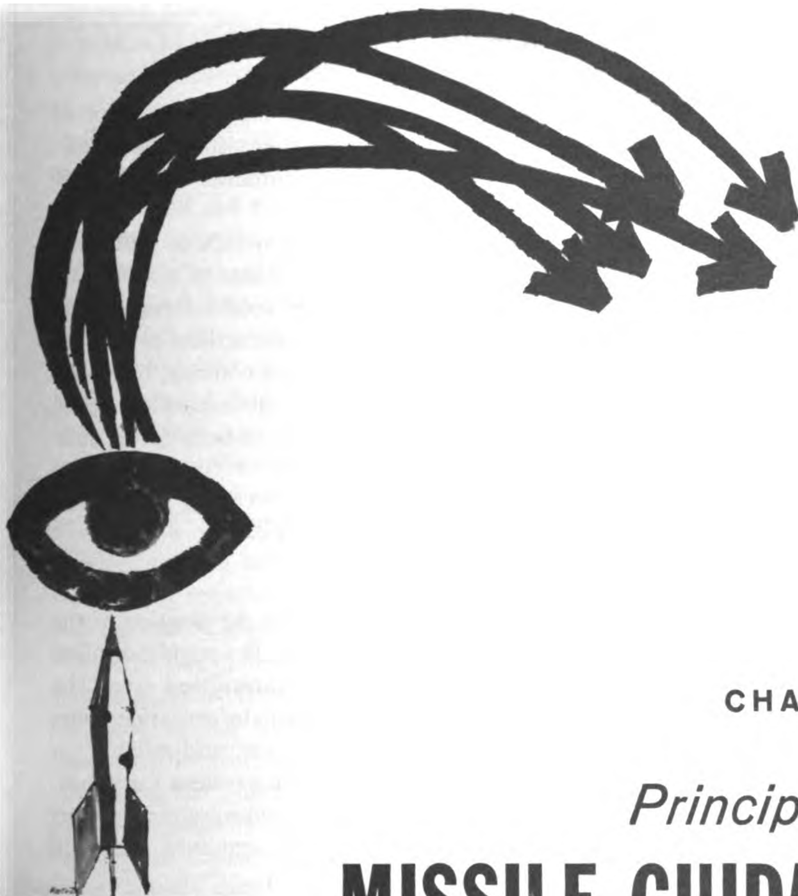
As we progressed into more advanced jet aircraft, ground equipment increased in importance. In the case of the B–58 jet bomber, for instance, it constituted some 15 percent of the over-all cost of a weapon system.

Power units operated from the ground were now essential for starting the aircraft, and malfunction of such units could easily cause a delay in the mission of the aircraft. Nevertheless, the pilot remained a most important part of any aircraft mission.

With the advent of ballistic missile and space weapon systems, the picture has changed almost completely.

Actually, a single failure of a small, inexpensive part used on the ground could well result in the abort and loss of a million dollar vehicle—and has. We have had faulty valves, connectors, or other minor mechanical or electronic malfunctions that resulted in a number of "spectacular failures." It follows logically that this is the area of our greatest concern in the question of logistical support of ballistic missiles.





CHAPTER 3

Principles of MISSILE GUIDANCE

A guided missile has been defined as a space-traversing unmanned vehicle which carries within itself the means for controlling its flight path. A guidance system is that group of components which is the means for controlling the missile's flight path. Some of the system's elements may be external to the missile, such as at the launch site, enroute to the target, or at the target itself. The missile guidance system is essentially a "series" device in that each element must function properly in order that the system as a whole will operate correctly. For this reason, reliability in operation of each element within the

◀ **A 20,000-lb. thrust rocket engine is inspected on its test stand.**

guidance system is requisite to predictable accuracy and the kill probability of the missile weapon system.

BASIC PRINCIPLES

The guidance system in a missile can be compared to the human pilot of an airplane. One guidance system uses an optical device that guides the missile to the target in much the same way as a pilot, using landmarks for bearings, guides a plane to a landing field.

If landmarks are obscured, the pilot must use another system of guidance. He could, for example, use radio beams. One missile guidance system uses radio or radar beams for guidance; another uses radio to send information to the missile, just as a ground control station might send instructions to a pilot.

We have mentioned radio and radar as primary guidance controls, but these are not the only methods by which a missile trajectory can be controlled. Heat, light, television, the earth's magnetic field, and sound have all been found suitable for specific guidance purposes.

COMPONENTS OF GUIDANCE SYSTEMS

General Requirements

A missile guidance system involves a means of determining the position of the missile in relation to known points. The system may obtain the required information from the missile itself, it may use information transmitted from the launching station or other control point, or it may obtain information from the target itself. The guidance system must be stable, accurate, and reliable.

In order to achieve these basic requirements, the guidance system must contain components that will sense guidance information from some source, convert the information into usable form, and activate a control sequence that will move the flight control surfaces on the missile.

Because it is difficult to separate the control and guidance operations, we will go through the entire guidance and control system. However, the flight control section is concerned with flight stability. Missile accuracy is primarily a function of the guidance section. Missile reliability depends on both sections. We will list the components and briefly describe the basic function of each before going into the individual types of guidance systems.

Components

Normally a guidance and control system includes sensing, computing, directing, stabilizing, and servocontrol components (also called controllers and actuators). The guidance and control system must measure the position of the missile relative to the target and cause whatever changes are required in the flight path to cause the missile to hit the target. Wan Hoo, a Chinese scholar,

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CHAPTER FOOTNOTE: Portions of this chapter dealing with computers, automatic celestial navigation, inertial guidance, and hyperbolic navigation have been adapted from *The Dawning Space Age,* published by the Civil Air Patrol, by permission.

is credited with engineering the first truly guided missile about 1500. Wan Hoo strapped himself in a chair equipped with 47 large rockets. Then, holding two kites in his hands, he ordered the rockets ignited. The launching was magnificent and Wan Hoo disappeared in a burst of flame and smoke. Although Wan Hoo's launching was considered a failure, in that Wan Hoo was never seen again, much valuable data was acquired even as in our present day launching mishaps. Wan Hoo's method was simplicity in itself—but his missile contained all of the elements required in a missile guidance and control system: a sensor, computer, director, stabilizer, and a servocontrol. Wan Hoo's eyes and ears acted as the sensor. His eyes detected electromagnetic radiation in the form of light and sensed or measured the position of his flight path. His ears sensed the vertical component or attitude of his missile. Wan Hoo's brain was a computer which received the signals from his sensor, his eyes and ears, and converted these signals into error signals. Wan Hoo combined the director and stabilizer functions in the rocket stabilization rods, and possibly his pig tail also contributed to these functions. The director maintains direction by controlling yaw and the stabilizer controls pitch and roll. The final component of a missile guidance system, a servocontrol, Wan Hoo provided in his arm muscles and the two kites. The error signal from the computer, his brain, went to the arm muscles causing the control surfaces, the kites, to change position, thereby controlling the flight path.

Present-day guidance systems have, of course, progressed far beyond the crude system of Wan Hoo. Present sensor devices include the use of electromagnetic radiation in the form of radio and radar emissions, infrared devices, visible light, and inertial devices such as gyroscopes and accelerometers. Wan Hoo's computer, his brain, would be too slow, too erratic, and far too unreliable to function properly in a present-day guidance system. Present-day computers require information inputs from the sensor and convert the information to usable form, usually digital. Memory circuits store the input data until it is needed. Memory circuits also provide the what, how, and when for the use of the input data. A calculator and computer perform necessary calculations from the input data and compare the results with the desired flight path information from a programer.

Present-day servocontrol components use electrical, hydraulic and pneumatic power to actuate flight controls. The servocontrol consists of an amplifier to amplify the small error signal from the computer and convert it to usable power, and some type of actuator to convert the amplified error signal to mechanical power for flight control positioning. The function of a director and a stabilizer are generally found embodied in the airframe or are separately controlled by the computer, servocontrol, autopilot method.

Sensor

In some respects the sensor element is the most important section of the guidance system because it detects the form of energy (heat, light, sound, or electromagnetic) being used to guide the missile. The type of sensor used will be

determined by such factors as maximum operating range, operating conditions, the kind of information needed, required accuracy, viewing angle and size and weight restrictions, and finally the type of target, and whether stationary or moving. Some missiles use more than one type of sensing device. All sensors have advantages and disadvantages. Some are particularly suited for specific application and totally unsuited for others. Guidance systems are often identified by the type of sensor element employed.

The signals detected by the sensor must be compared with known physical references such as voltage, time, space, gravity, the earth's magnetic field, barometric pressure, and the position of the missile frame. The sensor signal and a reference signal are compared by a computer, which will generate an error signal if a course correction is necessary. The error signal then operates the missile control system.

When an electromagnetic source, such as radio or radar, is used to guide the missile, an antenna and a receiver are installed in the missile to form the sensor.

Gyroscopes are used for space reference. A reference plan is established in space, and the gyro senses any change from that reference.

The earth's gravity can be used as a reference; a pendulum can sense the direction of the gravitational force. Some gyros are arranged for vertical reference by a pendulous pickoff and erection system. Gyros used in this manner are called vertical gyro; they may be used to control the pitch and roll of the missile (Fig. 13).

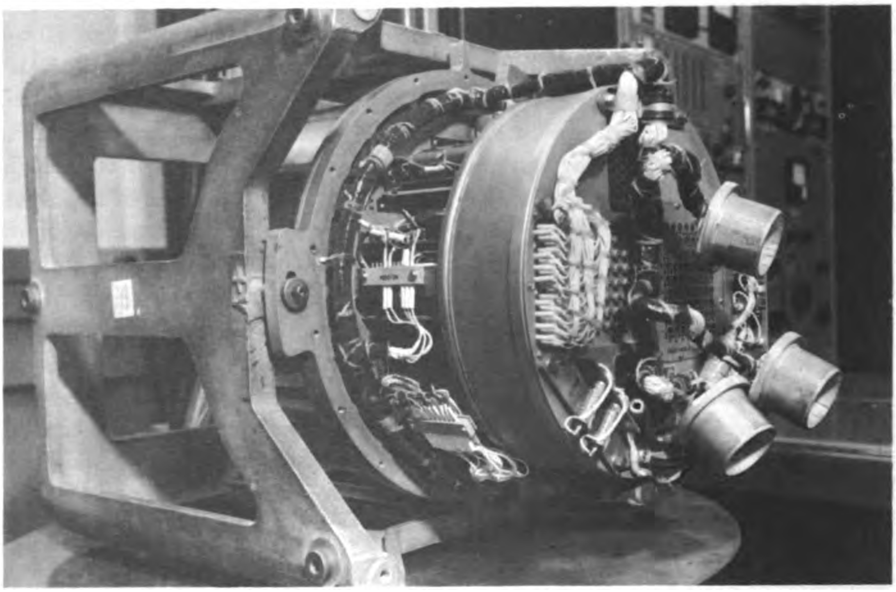


FIGURE 13. The guidance reference system that provides pitch-and-roll programming and three-axis reference for the guidance and control of the Titan missile. The Titan system consists of three hermetic integrating gyroscopes, a pitch-and-roll programmer, and an electronically controlled timer.

An instrument called a flux valve has the ability to sense the earth's magnetic field, and can be used for guidance. The primary purpose of this device is to keep a directional gyro on a given magnetic heading. A gyro operated in this manner may be used to govern the yaw controls of a missile.

Barometric pressure can be used to determine altitude. A guided missile that is set to travel at a predetermined altitude may use an altimeter to sense barometric pressure. Should the missile deviate from the desired altitude, an error signal will be generated and fed to the control section.

Another pressure-type sensor is used to determine airspeed. It compares static barometric air pressure with ram air pressure. The difference between these two pressures provides an air speed indication.

The axis of the missile frame is used as a reference to measure the displacement of the missile control surfaces. (The movement of the control surfaces cannot be referenced to the vertical, or to a given heading, because the reference would change when the missile position changes.)

Each of the sensor units we have discussed produces an output; in most cases this output is a voltage. A computer is used to compare the sensor output voltage with the reference voltage. If the missile is off course, the two voltages will not be the same. The computer will then generate an error signal, which will be used to operate the servocontrol which in turn operates the missile control surface and brings the missile back on course.

Computer

A computer is necessary in missile guidance systems in order to calculate course corrections rapidly. In one type of missile the computer is simply a mixing circuit. On the other hand, the computers used at launching sites may be large consoles with many stages.

An important function of a computer is the coding and decoding of information relating to the missile trajectory. In order to make the proper selections, the computer uses discriminator circuits to select pulses of the proper width, amplitude, frequency, phase, or time difference, and reject all other pulses. By using a number of different discriminators, a wide variety of pulse characteristics can be handled. The discriminator is relatively insensitive to man made electrical noises and atmospheric static.

A second important computer function is to compare the signals from the sensor and reference units, to compute the missile's position with respect to the desired reference planes, and to generate error-signal voltages of the polarity and amplitude required to bring the missile back on course.

Computers may be divided, according to the way they operate, into two classes: analog and digital. An analog computer deals with quantities that are continuously variable. A target bearing angle, for example, is such a quantity; in an analog computer, such a quantity can be represented with considerable accuracy by a voltage, or by the angle of rotation of a shaft. Digital computers, on the other hand, deal only with quantities that vary by distinct steps. For example, an angle might be represented as either 67° or 68°, but not as anything

between those values. (A more complex computer might represent the same angle as either 67.43° or 67.44°, but would be incapable of dealing with any value between those two.) An ordinary slide rule is a simple analog computer, in which the position of the slide is "analogous" to the quantity represented. A desk calculating machine, or an abacus, is a simple digital computer.

An analog computer may be mechanical or electrical. This type of computer operates upon physical quantities that represent the mathematical variables of a problem. Sometimes it is easier to manipulate physical quantities representative of mathematical variables than it is to operate directly with these latter.

In a mechanical analog computer, the input and output variables are usually represented by angles of shaft rotation. The computer performs its various calculations through the movement of shafts, gear trains, slides, linkages, and other mechanical devices. Computers using these principles have been used to solve navigation and fire control problems for a number of years.

In an electronic analog computer, the input and output variables are represented by voltages, and the computations are performed by electronic circuits. A type of electronic analog computer that has proved useful in missile design is the differential analyzer. This device is sometimes called a simulator, because it can be given electrical inputs that simulate both the characteristics of a proposed missile and the conditions under which it will operate. The action of the computer will then show how the proposed missile will perform under the specified conditions. It is thus possible to test new missile designs without building actual prototype missiles, and this procedure results in a considerable saving in both time and money.

A digital computer is electronic. It uses numbers in the form of digits in its mathematical computations. Digital computers are used in missile guidance systems and employ the binary system of numbers rather than the commonly used decimal system based upon the scale of 10.

The binary system uses only two digits: 1 and 0. Hence the digit 2 of the decimal system would be represented by 10 of the binary system; 4 of the decimal system would be represented by 100 of the binary system. In fact, any sequence of 1's and 0's in the binary indicates that the digit 2 of the decimal system is raised to some power. For example, 1,000 indicates 2^3; 10,000 indicates 2^4; 100,000 indicates 2^5, or the number 32 in the decimal system. Just as any number may be expressed in powers of decimal system 10 plus any remaining digit, so can any number be expressed in powers of the binary system 10 plus the digit 1. Thus 10,101 in the binary system would equal $2^5+0^4+2^3+0^2+1$, or 41 in the decimal system.

The binary number system enables an "on-off" electronic system to exercise a computing function on input data from a missile sensor. Such a device need represent only "go" or "no go" conditions. A closed relay would represent a go condition which could represent the binary digit 1; the relay in the open position would represent the no go condition which, in turn, could represent the binary 0.

Both analog and digital computers have applications in guided missiles and their associated ground equipment.

The Computer and Its Related Units

Deviations of such controllable items as a missile's attitude, flight direction speed, and accelerations from desired conditions are detected by the sensor of the missile guidance system (Fig. 14). When a deviation from a desired condition occurs, the sensing unit generates an output signal which is known as an "error."

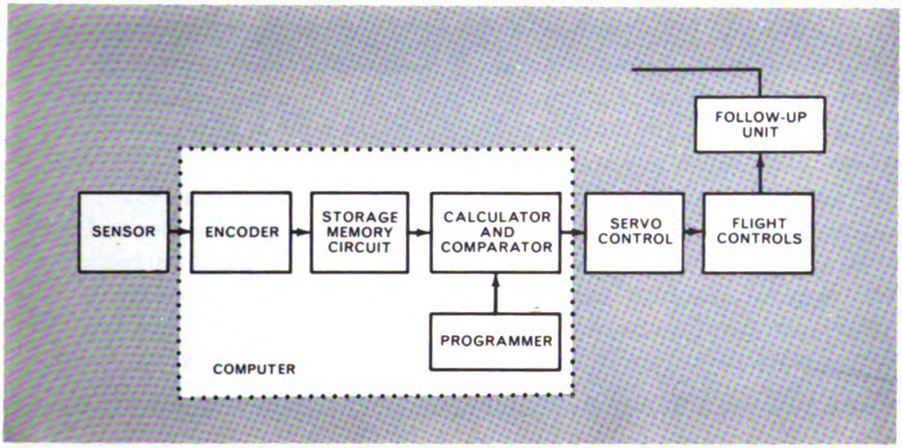


FIGURE 14. Computer diagram.

A component of the sensor unit, called the pickoff, is used to convert the detected deviations into appropriate signals. These signals are very seldom referred directly to the servocontrol to bring about corrections of the deviations. Generally, they must be acted upon first by a computer. Then, before these signals can bring about proper functioning of correcting control devices, the computer output may need to be strengthened by an amplifier.

Computer units for missile guidance systems may be simple or they may be very complex. The degree of a computer's complexity is determined by the nature of the function it is to perform. For example, the computer of a passive homing guidance system, such as that used by the Sidewinder, may consist of a mixing circuit only, while the computer of a large-scale ground installation, such as that required for Nike operations, requires the use of many computer components. Computers of missile guidance and control systems generally incorporate four kinds of devices: mixers, integrators, comparators, and differentiators (rate systems).

The mixer is a device that combines information from two or more sources. In instances where separate sensors and references are used to detect deviations of each of a number of variable factors, the mixer would combine signals from each in a manner that would obtain the proper correction. For example, to

control the attitude of a missile around its lateral axis, error signals from senior units monitoring the variables affecting pitch, such as speed, attitude, and altitude, would be mixed so that control device actuation would be influenced by each in proper proportion.

The integrator is a device that performs mathematical operations on input signals to the computer in a manner that obtains new information of importance. For example, after the accelerometer measures the missile's acceleration, acceleration and time signals are fed to an integrator unit which computes the missile's velocity ($v=at$). Velocity and time signals subsequently are fed to a second integrator unit which computes distance traveled ($D=\frac{vt}{2}$).

The duration of the missile's flight, represented by t in the formula, can be found easily by the use of a timing device (clock). Velocity, you will remember, is the rate of change in distance traveled with the lapse of time. Acceleration is the rate of change in velocity with the lapse of time.

The data from the accelerometer and clock are fed to the integrator which automatically calculates the missile's velocity and how far it has traveled at any instant. In turn, these data are operated upon by another unit of the computer—the comparator—which automatically calculates the time-to-target by subtracting the distance traveled from the distance between origin and target and then dividing the remainder by the present velocity. The equation for this operation is $\frac{D-D_t}{v}=t_r$. D represents total distance; D_t, distance traveled at a given instant; v, velocity; and t_r, time to reach the target.

The differentiator, like the integrator, performs a mathematical operation on an input signal. Like the integrator, the rate system mathematically produces information based upon relationships existing among variables considered. However, the new information produced by the rate system has to do with the rapidity with which a deviation detected by a sensor takes place. These rate signals have an important use in the missile guidance system. They prevent and restrain missile oscillation by combining error signal with a rate-of-change signal to obtain a leading signal. The leading signal causes control devices to act so that large deviations are checked before they begin. The differentiator uses the rate of deviation signal to increase the corrective effect of the system.

Computers used in missile guidance systems can operate properly only when their components are capable of performing definite functions. An input unit must receive and decode information. A logic unit accomplishes digital computations based upon such data. A memory unit stores essential data until the needs for these arise. An output unit transmits these data in a proper form to an actuating device as they are needed to guide the missile along a proper flight path, regulate fuel flow, shut off the engine or dive the missile into its target, or in the case of a ballistic missile, separate the warhead so that it may continue along the established ballistic trajectory.

Computer units may be classified in terms of their functions as these relate to a missile's flight, or they may be grouped in accord with their operating

principle. Consequently, computers may be referred to as pre-launch, launch, azimuth, elevation, program, or dive-angle computers. Or they may be termed analog or digital.

Servo-control

It may be necessary to increase either the voltage or intensity of the error signals from the computer before these are referred to the equipment which operates the correcting devices. Voltage and power amplifiers are used in guidance systems for such purpose, and are a part of the servo-control (Fig. 15).

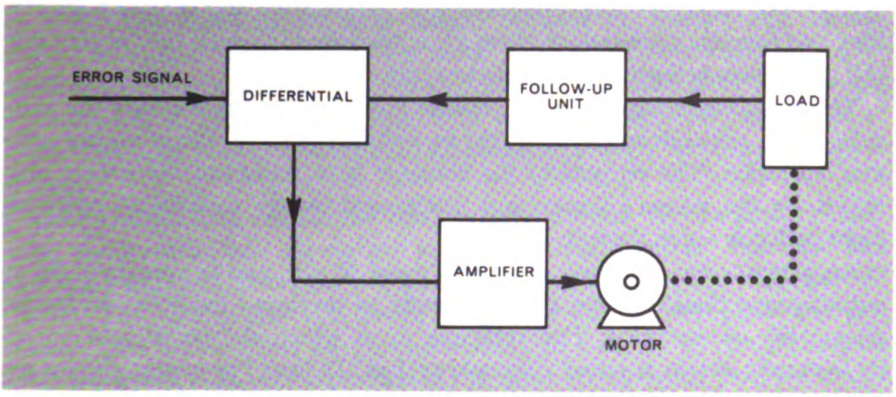


FIGURE 15. Simple servo-control.

A transformer is a simple, familiar device that can increase an alternating current voltage. The voltage across the secondary winding may be many times as high as the voltage applied to the primary. But the current available in the secondary circuit is proportionately smaller than that applied to the primary, so that there is no increase in power. There is no device that will give out more power than you put into it; in other words, no one gets something for nothing.

In an amplifier, the small power available in the input signal is used to control the amount of power that is supplied from another source. Thus, in a sense, a relay or a switch is an amplifying device. A small amount of power applied to the relay primary, or to the switch handle, will close the contacts and thus apply a much larger amount of power to the load. But a switch or relay is an all-or-nothing device; the contacts are either open or closed. Many missile applications require an amplifier whose output is not only greater than the input, but also proportional to the input. For example, let us say that a sensor provides a one-volt input to an amplifier, and the amplifier output is 15 volts. Then, if the sensor supplies a three-volt input, the amplifier output must be 45 volts.

Electronic amplifier circuits can be designed to give proportional amplification for a limited range of input voltages. Electronic amplifiers have become familiar devices. An electronic amplifier is used to amplify the output of a

record-player pickup to the power level required to drive a loudspeaker cone. Electronic amplifiers are used to amplify the signals picked up by a radio antenna. (But note that, in both cases, the actual power of the input signal is not increased. The input power is used simply to control the power supplied from another source—either batteries or the A.C. line.) All electronic amplifiers are based upon the principles of power conversion obtainable in such devices as vacuum tubes, transistors and in some instances magnetic amplifying devices. Transistors are replacing vacuum tubes in many missile applications because of their particular advantages such as reduced size and weight, less power consumption, long life, and ability to withstand shock and vibration. However, due to inherent disadvantages such as temperature and radiation sensitivities, and frequency limitations, there are applications in which the vacuum tube will continue to be used in preference to a transistor.

The servocontrol equipment of missile guidance systems includes the actuator, which responds to error signals, as well as the units which control actuator operation. The purpose of the actuator is to transform the energy originated by the system's sensor into mechanical energy capable of operating flight path correction devices.

An actuator must respond rapidly to input signals, and it must produce an output proportional in type and magnitude to the input methods: hydraulic, pneumatic, or electrical. The principle upon which the transfer of energy by hydraulic means is based is known as Pascal's law. Pneumatic systems use air as the energy transfer medium. Motors are generally used as actuators in a system that transfers electrical energy into mechanical energy. In some systems, combination-type energy transfer systems are used.

Units which control actuator operation include solenoids, relay switches, transfer valves, and various other transducers. A solenoid consists of a coil of wire wound around a hollow cylinder and an iron core free to move within the cylinder. A current flowing through the solenoid coil tends to center the core into the coil. Consequently, solenoids can be used to operate relay switches, hydraulic valves, and pneumatic valves.

So that energy may be transferred from the actuator to the control device, some type of mechanical linkage must be used. It is possible, through proper designing of such linkage, to increase the effectiveness of the energy transfer. Mechanical linking devices consist of gears, levers, and cables so arranged that they transfer actuator movement (linear or rotating) to the controlling device. The movement caused in the control device must be of proper magnitude and direction. When the direction of the actuator output is reversed, mechanical linkage components must reverse the direction of the controlling device.

Control devices and mechanisms employed to keep a missile on its flight path, to correct its deviations from a proper course, and to perform such other functions as will bring a missile into contact with its target, differ for different types of missiles. In general, aerodynamic missiles use one type of guidance controls, and ballistic missiles use another type of such controls.

Aerodynamic Controls

Aerodynamic missiles and some ballistic missiles, in common with aircraft, make use of fixed guide fins, which perform the functions of horizontal and vertical stabilizers. When airfoils are employed by missiles, their configuration differs somewhat from that of the fixed control surfaces of an aircraft, since missile control surfaces are designed for very high-speed flight.

The primary controls of aerodynamic missiles are ailerons, elevators, and rudders. Secondary control surfaces are tabs, spoilers, and slots. A tab is hinged to the trailing edge of elevator or rudder. Moving the tab in one direction enlists the help of airflow when it is desired to move a control surface in the other direction. Spoilers are flaps hinged between the leading and trailing edge of an airfoil. When spoilers are raised into the airflow around an airfoil, the lifting power of the latter is reduced. Slots are located along the leading edges of airfoils. In normal cruising flight they are closed. At high angles of attack they open and increase the lift characteristics of an aerodynamic missile in flight.

Some aerodynamic missiles use dual purpose controls. Terms such as ailervator, ruddervator, and elevon are applied to these controls. Ailervator and elevon are different names for a device which acts to give both pitch and roll control. The ruddervator is a device which acts to give both pitch and yaw control. One missile flight control mechanism, in order to correct flight path deviation errors, changes the position of the entire airfoil rather than a movable section of it. At very high speeds, the control movement required to bring about a change in aircraft or missile attitude is very slight when compared with that needed to bring about a similar change at low speeds.

Control of Ballistic Missiles

After a missile leaves the atmosphere it can make no further use of airfoils for either guidance or lifting purposes. Moreover, the high-speed aerodynamic controls used by supersonic aerodynamic missiles are not completely effective during the launching stage of missile flight. Hence, control devices other than aerodynamic have been developed. Among these are exhaust vanes, deflection charge controls, and gimbaled engines.

Exhaust vanes are used to deflect the exhaust gases of jet or rocket engines. When an exhaust vane is moved into the exhaust stream, thrust is directed in opposition to the plane of the exhaust vane surface. The materials from which exhaust vanes are made must be highly heat resistant.

Deflection charge controls are small jet nozzles placed at appropriate points about the missile fuselage. Change in a missile's attitude may be brought about by using one or another of these auxiliary jets to change the direction of thrust.

The mounting of the missile engine by using a gimbal which permits it to direct its thrust in any direction provides still another method of missile control. This method requires powerful control equipment.

TYPES OF GUIDANCE SYSTEMS

The type of guidance system, i.e., the combination of a particular type of sensor computer and servocontrol, used on a missile is in large measure determined by the intended use of the missile. Some types of guidance systems can be used against moving targets while others are limited in application to use against stationary targets. Some guidance systems can be adapted for use against both types of targets. The various types of guidance systems can be classified generally as:

Seeker or homing guidance
Command guidance
Position fixing guidance
Dead reckoning or inertial guidance

Seeker or Homing Guidance

The expression "seeker" or "homing guidance" is used to describe a missile system that can "see" the target by some means, and then by sending commands to its own control surfaces, guide itself to the target. (Use of the word "see" in this context does not necessarily mean that an optical system is used. It simply means that the target is detected by one or more of the sensing systems.)

Basic Principles.—Some seeker or homing guidance systems are based on the use of the characteritics of the target itself as a means of attracting the missile. In other words, the target becomes a lure in much the same manner as a strong light attracts bugs at night. Just as certain lights attract more bugs than others, certain target characteristics provide more effective homing information than others. And some target characteristics are such that missiles depending on them for homing guidance are very susceptible to countermeasures.

Other homing systems illuminate the target by radar or other electromagnetic means, and use the signals reflected by the target for homing guidance.

The various seeker or homing guidance systems have been divided into active, semiactive and passive classes. The name of the class indicates the type of guidance in use.

An active seeker system contains both a transmitter and receiver within the missile and homes on a reflected signal. Because of the present space-weight limitations, only a small power supply and a small antenna system are available, thereby limiting the range potential of this system.

A semiactive seeker system contains only a receiver within the missile and homes on the echo signal of a target which is illuminated from a remote point. The remote illumination, radar or visible light, can emanate from such sources as a delivery aircraft, a ground station, or a ship. This system provides a greater range potential because the transmitted power is not limited by the space-weight limitation of the missile.

A passive seeker system homes on energy transmitted by the target itself. Infrared, sound, visible light, or radar and radio radiations are forms of energy which can be used for homing with a passive seeker. This system is potentially the most accurate, and has a high potential for extended range.

Since this system is not dependent upon reflection or echoes but uses only the characteristics peculiar to a particular target, it is also the least susceptible to countermeasures. Of the possible sources of radiant energy for this system, infrared has been developed to the greatest extent. Lead sulphide, lead telluride, lead selenide and gas cells containing nitrous oxide are comon detection cells used with infrared passive seekers. The range of the present systems is limited primarily by the sensitivity of the detection cells and attenuation of the infrared by moisture and carbon dioxide. These factors cause the present infrared systems to be primarily high altitude, fair weather devices.

Command Guidance

The term command guidance means that intelligence (commands) is transmitted from an outside source to the missile while the missile is in flight (Fig. 16).

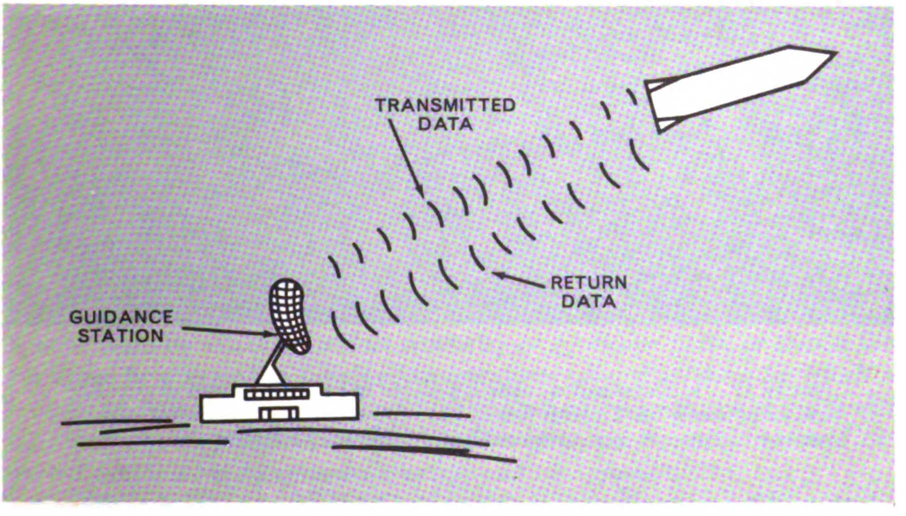


FIGURE 16. Command guidance.

A command guidance system incorporates two links between the missile and the control point. One, an information link, enables the control point to determine the position of the missile; the other, the command link, makes it possible for the control point to correct any deviations from the desired path.

BASIC PRINCIPLE.—When command guidance is used, a ground, shipboard, or airborne station determines the position of the missile by radar tracking equipment or other means. It determines the error, if any, between the actual position of the missile and the desired position. It then sends out control impulses (commands) to bring the missile to the desired course. If the flight path is long, and a large part of the path is over friendly territory or waters, several stations might track the missile as it comes into their range. These stations would then send commands to the missile to correct any deviations from the desired course.

The simplest form of command guidance uses wires actually attached to the missile and to the signal device. This system is similar to a control-line model airplane. The obvious limitation in this system is range. The more common form of command guidance uses radio or radar signals originating at a guidance station located on the ground or possibly in a delivery aircraft. The missile contains the receiver and servo-control components of the system, while the guidance station contains the transmitter and computer components (Fig. 16). This system

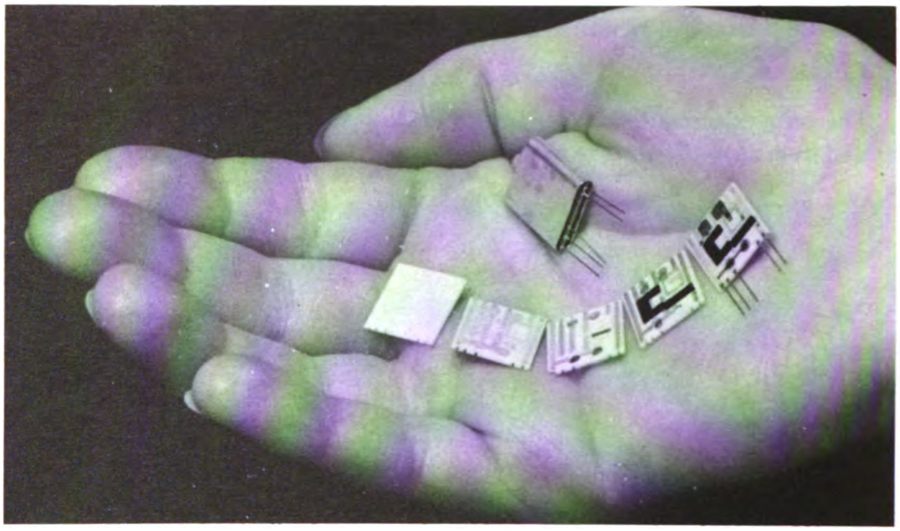


FIGURE 17. Miniaturization made it possible to create a pattern of circuitry and components on a plastic base wafer. A series of these wafers can be stacked together to form a desired unit, or module, complete with circuity.

can be used for ballistic missile guidance, in which case a radar determines the missile's position through range, azimuth, and elevation and the computer determines incremental range, azimuth, elevation, and velocity and calculates necessary flight path corrections. The corrections are then sent to the missile by the radar, and the servo-control receiver components cause the required changes. In a ballistic missile, the command guidance positions the missile at the proper point in space and with the proper velocity so that the missile warhead will achieve the desired ballistic trajectory upon termination of the guidance portion of the missile's flight.

Position Fixing Guidance

Position fixing guidance systems use terrestrial or celestial reference points to fix the position of the missile.

Celestial navigation, the art of fixing a geographical position by reference to stars, was practiced centuries ago by those who sailed the oceans beyond the sight of coastal landmarks. Pilots and navigators of aircraft adapted it to their needs. The dawn of the space age—which might also be called the age of auto-

mation—discovers that man has devised automatic means of navigating by reference to the stars. One system of celestial navigation is continually referenced by stellar fixes.

AUTOMATIC CELESTIAL NAVIGATION.—A missile guidance system using stellar references incorporates devices for measuring the altitudes of stars in relation to the horizon. Usually two sextants, which operate to obtain a simultaneous fix on two stars, are used. Just as the aircraft navigator who uses celestial navigation must employ data from charts and star tables, so must the automatic celestial navigator employ such data. Before the system can use them, the data must be transformed into a memory form. This memory form may be electronic, magnetic, or mechanical, whichever is appropriate to a specific system. Some type of time recording device (clock) is also an essential part of the sensing unit. From the data obtained by the stellar detection unit, computations of corrections needed to overcome errors (such as yaw, pitch, and roll) are made. Signals relayed by the computer to actuators operating controls keep the missile on the proper flight path.

STELLAR SUPERVISED INERTIAL GUIDANCE.—In the stellar supervised inertial guidance sensing unit, the major role is played by inertial guidance devices. Periodic stellar checks are taken to supplement the guidance intelligence of the inertial sensing unit. These checks may become necessary because of errors which may result from gyro drift. Gyro drift results from faults in the gyroscope unit which cause a change in the position of the spin axis. In such instances, the line-of-direction of the gyro does not point correctly. Three causes of gyro drift are an unbalanced gyroscope, bearing friction, and a rotating gimbal. Should there be a lack of perfect symmetry of gyroscope parts, or should the gyroscope be operated at speeds or temperatures other than those for which it is designed, imbalance results. Should the gimbals of the gyroscope be positioned incorrectly, bearing friction results. Should a gimbal rotate, the inertia of the gimbal causes a loss of gyroscopic energy and consequent drift.

Gyro drift is not constant; it is likely to vary in both direction and magnitude. It is difficult, consequently, for the components of the inertial system to predict the resulting error. Such random errors of only 1° of arc per hour would cause a missile, after an hour's flight, to miss its target by 60 miles.

Present types of gyroscopes are greatly superior and much more precisely manufactured than those available only a few years ago. Gyroscope manufacturers are succeeding in the elimination of random drift. However, the incorporation of stellar supervision in a missile guidance system appears to be a refinement that contributes to the accuracy of the long-range missile guidance system.

RADIO NAVIGATION MISSILE GUIDANCE SYSTEMS

Two types of radio navigation are applicable to missile guidance: circular and hyperbolic. In the circular method of radio navigation, position is determined by finding the location of an aircraft or missile in flight from two or more

radio stations whose locations are known. A line describing this constant difference will be a hyperbola.

Circular Navigation and Missile Guidance

The circular navigation type of missile guidance system requires two radio stations (called slave stations) located outside the missile and a master station within the missile. The missile is caused to fly along a circular path at a constant distance from one of the slave stations. The time taken by signals transmitted by the missile's master station to reach this slave station and return to the missile is used to determine the missile's distance from the centered slave station. This information is compared with the fixed range in the range comparator, and signals are thereby generated, causing the missile to fly along a circle which goes through the target.

The missile flies at a predetermined altitude. Altimeter signals are compared with a fixed altitude set into the computer. Proper signals, so determined, are relayed to controls which keep the missile flying at the correct altitude.

The second slave station determines the point at which terminal guidance begins. When the range from this station to the missile coincides with the preset range in the missile computer, one of the homing guidance mechanisms or a terminal inertial system assumes guidance control.

Hyperbolic Navigation and Missile Guidance

A hyperbolic navigation type of missile guidance system employs two radio stations located at fixed ground locations a considerable distance apart (Fig. 18).

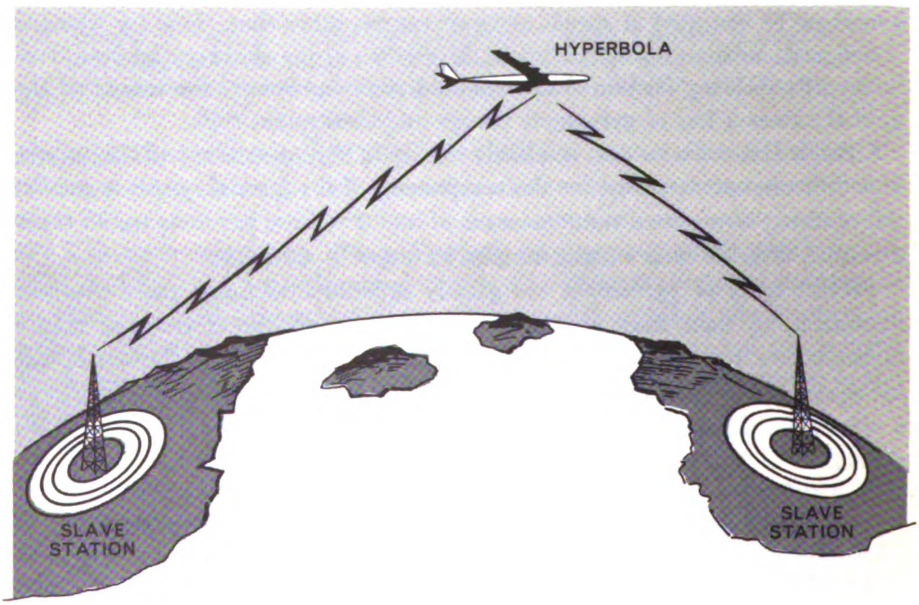


FIGURE 18. Hyperbolic guidance system.

The missile also contains radio receiving and transmitting equipment. A signal transmitted from the missile is received at each of the two ground (slave) stations. Each of the two slave stations then transmits a signal which is received by the missile's master station. A time comparison of the two signals received by the missile provides guidance information and enables it to fly a course of constant-distance difference between the two slave stations, which brings it to its target.

The constant-distance differences between the two slave stations as determined by the transmitted signals received by the missile's station may be plotted as a hyperbola. The slave stations must operate on different frequencies and the missile's station must be equipped with two receivers.

As the signals from the slave stations are received in the missile they are compared. When the time difference indicates that the missile is not flying along the correct hyperbola to the target, an appropriate error signal is generated which causes the missile to turn right or left and so return to the correct course.

This system employs an altimeter system which operates to maintain proper missile altitude much as that used by the circular navigation missile guidance system. The arrival of the missile over the target is determined by the missile's computer. The transmitted signal from the missile is time-compared with a signal received from one of the slave stations. When this signal agrees with a preset time in the missile's computer which represents the distance from this slave station to the target, terminal guidance assumes control.

INERTIAL GUIDANCE

Inertial guidance systems are looked upon by engineers and scientists as the ultimate in guidance for use against stationary targets. Inertial guidance is so accurate that the submarine Nautilus on its first cruise under the polar ice cap was able to use an inertial navigation system that was originally developed for use in long-range guided missiles. The inertial guidance system differs from all other guidance systems in that it can determine its position while moving by using information derived entirely from within its vehicle. After the positions of launching base and target have been set into the system, and the system has been placed in operation, it can determine the flight attitude and geographical position of its vehicle, the distance it has traveled, and the distance and direction to its destination. Since the position of the target must be known, a missile using the inertial system cannot be launched against a moving target unless a homing guidance type system is also incorporated within the missile to guide its final flight phase.

Early inertial guidance systems controlled missiles in altitude by using an altimeter and in azimuth by using a gyroscope whose axis was set to the desired heading. The ranges of such missiles were measured by some type of mileage recording device. One simple inertial system used in World War II controlled the missile in azimuth along a predetermined course by means of a gyroscope. The trajectory in elevation to be followed by this missile was computed at origin. The proper trajectory was obtained by means of another gyroscope

whose programed precession changed the pitch angle of the missile when necessary. In this system, the missile's heading and corrections for the effects of wind and gravity were preset before launching. However, once a missile using such a guidance system was in flight, a factor such as wind change might cause a deviation from the proper course.

The modern inertial guidance system is designed to compensate for all unpredictable factors influencing missiles in flight. The fact that the system is self-contained gives it many operational advantages. It is not subject to enemy countermeasures, it is maneuverable, and it can operate anywhere at any time in all kinds of weather and temperature conditions and at any altitude. Moreover, in its present stage of development, the inertial guidance system is generally accurate and reliable.

All types of inertial guidance systems contain four major components: an inertial platform, a computer, miscellaneous electromechanical devices such as those used to record launching and target positions, and a precisely regulated power supply to operate the platform devices. The heart of an inertial guidance system is its inertial platform. The most important devices contained by the platform are its accelerometers and gyroscopes (Fig. 19).

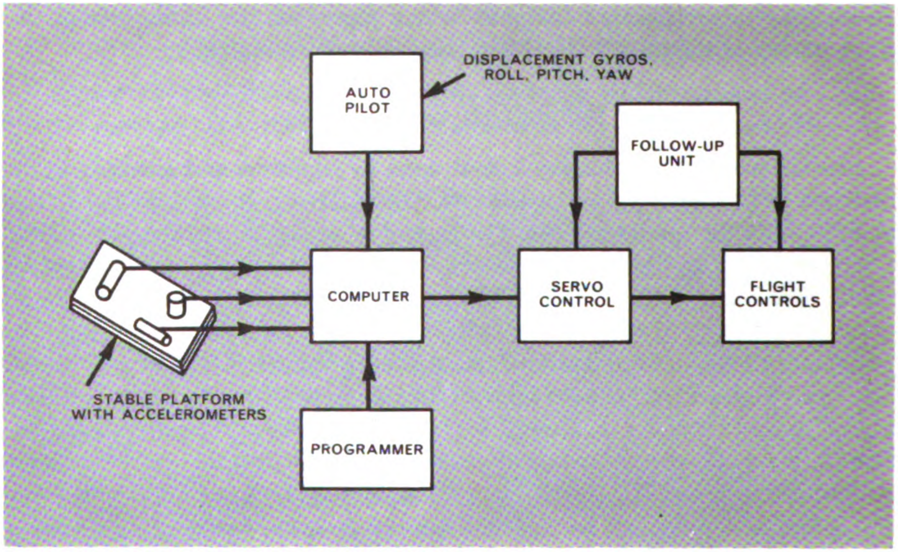


FIGURE 19. Inertial guidance system.

The Accelerometer

The primary function of an accelerometer is to measure the effects of forces acting upon a vehicle in flight. The engineers who designed the accelerometer took into account Newton's second law of motion. You will remember that Newton demonstrated that when a force acts upon an object, the object accelerates in the direction in which the force is applied. Newton found that such

acceleration is directly proportional to the force applied to an object and inversely proportional to the mass of the object. These relationships may be expressed by the equation $F = Ma$, where F represents force in pounds, M mass in slugs, and a acceleration in feet per second. Hence, after acceleration values and the mass of a body are found, the magnitude of the forces causing acceleration can also be found. Furthermore, acceleration measurements once computed can be converted into velocity values and distance traveled, and hence make it theoretically possible to calculate a vehicle's position at any instant during its travel.

It would be a rather easy matter to devise a simple accelerometer to enable the computation of the distance traveled by a vehicle if only one force were applied to the vehicle and if this force were applied in a single direction. The activating unit of such an accelerometer would be a small mass elastically suspended. The displacement of this mass would be proportional to its inertial reaction to an acceleration. (You will remember that for every action there is always an equal and opposite reaction.) Such an accelerometer could be used to determine the linear accelerations of any vehicle containing it. The magnitude of the displacement of the mass could be measured electrically, or by some other means, and from such measurements, distances traveled could be found.

Another type of simple accelerometer substitutes for the elastically suspended mass a pendulum supported by a pivot bearing. You can demonstrate the action of a pendulum accelerometer by using a plumb bob and line, such as surveyors and carpenters use, to find the direction of specific gravity (straight down) from a point on the earth's surface. If you hold one end of the plumb line in your hand, allowing the plumb bob to swing freely, and take a few steps forward, you will observe that the pendulum swings backward. It will always swing backward in line with the steps and at a rate and distance proportional to the speed and length of each step taken. That is to say, if you change the length and speed of the steps you take, the swinging motion of the pendulum changes accordingly.

In 1923, Schuler, a German scientist, discovered that although a pendulum type accelerometer, such as that described above, could be used to measure accurately rates of acceleration along a straight line, any change of direction would cause a violent pendulum deflection and therefore an inaccurate measurement. He also found that if the plum bob part of the pendulum could be located at the center of the earth so that it could not move, the suspension point of the pendulum could be moved in any direction without causing pendulum deflections and corresponding errors in accelerometer measurements. Theoretically, such a pendulum could be used to measure with accuracy both rates of acceleration and the directions of all external forces acting upon any vehicle to which it was attached. However, the length of the plumb line of such a pendulum would have to equal the radius of the earth (3,963 miles). Obviously, it would not be possible to devise or use a pendulum over 3,000 miles long.

Schuler, however, also discovered that the natural oscillation (swing) of this pendulum was 84 minutes, and that if an 84-minute oscillation were built into a short pendulum, it would behave like the 3,963-mile long pendulum.

The 84-minute pendulum type accelerometer also gives a continuous indication of the vertical along the path of its vehicle's flight. The vertical is a hypothetical line representing the force of gravity from the point of suspension of a pendulum toward the center of the earth. It is sometimes described as the direction of specific gravity. The vertical is unique for any point on the earth's surface. An accelerometer based upon the principle of the 84-minute pendulum not only provides a means for measuring accelerations, but also tends to indicate the local vertical regardless of the movements of the vehicle that carries it—a function whose importance is subsequently discussed.

Some inertial guidance systems use an unbalanced gyroscope to sense accelerations. This type of gyroscope incorporates pendulum characteristics. Accelerations about its sensitive axis precesses such a gyroscope at a rate proportional to the accelerations. The total angle of the gyroscope's displacement is proportional to the integral of acceleration, that is, to velocity. Accelerometers using unbalanced gyroscopes sensitive to accelerations are called integrating accelerometers. When they are used, the computer needs to make one integration only to find distance traveled.

The Gyroscope

Gyroscopes in an autopilot system make certain that a missile in flight assumes a proper attitude. The gyroscopes of the modern inertial guidance system also keep the accelerometers of this system in proper alignment.

A gyroscope (gyro) is a mechanical device containing an accurately balanced rotor. An axis around which this rotor spins passes through the center of gravity of the rotor. Gimbals are used to provide a mounting for the rotor and its axis, which permits the rotor of a free gyroscope to turn in any direction about its center of gravity (Fig. 20).

When the rotor of a gyroscope revolves at a high speed, the gyroscope assumes two significant characteristics. One of these is termed gyroscopic inertia (rigidity in space), and the other gyroscopic precession.

Gyroscopic inertia is the property of a gyroscope which resists a force tending to displace the rotor from the plane of its rotation. The strength of this resistance is determined by the amount and distribution of the rotor's weight and by the speed at which the rotor spins. Increased rigidity is obtained by adding weight or speed to the rotor and by distributing greater weight to the rotor's outer rim.

There are two types of gyroscopic precession: real and apparent. Real gyroscopic precession occurs when a force applied to the gyroscope causes the rotor assembly of the gyroscope to be displaced. The property of gyroscopic precession is such that the displacement is not at the point of the applied force but 90° from such point in the direction of rotor rotation. It should be noted that a force applied to the gyroscope at the center of gravity would not disturb the established position of the gyro spin axis. A spinning gyro can be moved in any direction in space, just as a gyro at rest can be moved, provided the gyro

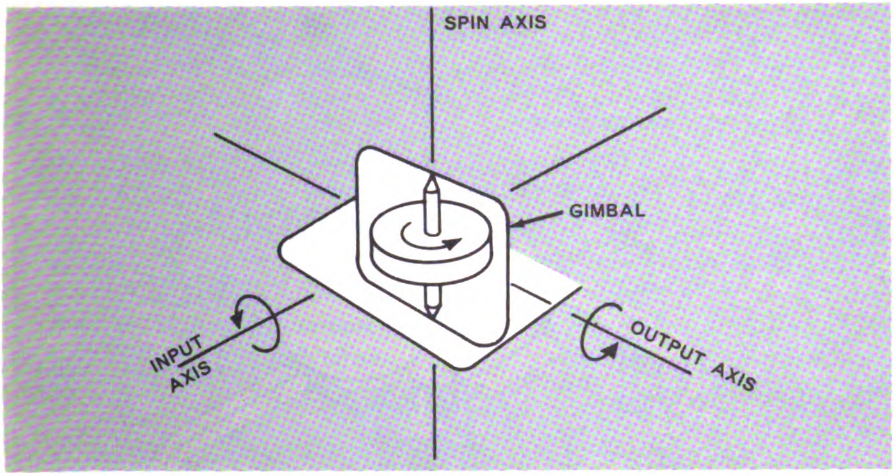


FIGURE 20. Gyroscope.

spin axis remains parallel to its original position in space. Consequently, although a spinning gyro provides stability, such stability relates only to planes containing its spin axis.

Apparent precession of a gyroscope occurs because gyroscopic inertia causes the gyro spin axis to become rigid in space, and because the rotating earth turns under the gyroscope, causing the gyro spin axis to gradually tilt or drift relative to the earth's surface. Since the earth rotates once each 24 hours, the rate of apparent gyro precession is 360° in 24 hours, or 15° in 1 hour. Before gyroscopes can be used as a reference over any extended period of time, some device must be used to keep the gyro spin axis in a fixed relation to the local vertical.

The Inertial Platform

The inertial platform provides support for the accelerometers and also an arrangement whereby accelerometers and gyroscopes can assist each other. An accelerometer can give accurate acceleration measurements only when the platform containing the accelerometers is kept horizontal, not to the earth's surface, but to an imaginary vertical line representing the direction of the force of gravity. Gyroscopes can keep the platform rigid in space, but under this circumstance the platform is not necessarily in proper position. Signals must be fed continuously to gyro torque motors which precess the gyroscopes, hence rotate the platform, keeping it alined to the local vertical. One of these signals is proportional to the velocity output of the first integrator; the second signal is introduced to compensate for the earth's rotation. The source of the first signal is an accelerometer. Thus, the gyroscopes keep the inertial platform in position so that accelerometers help to keep the gyroscopes informed of changes in position which they must make to keep the platform in proper alignment (Fig. 21).

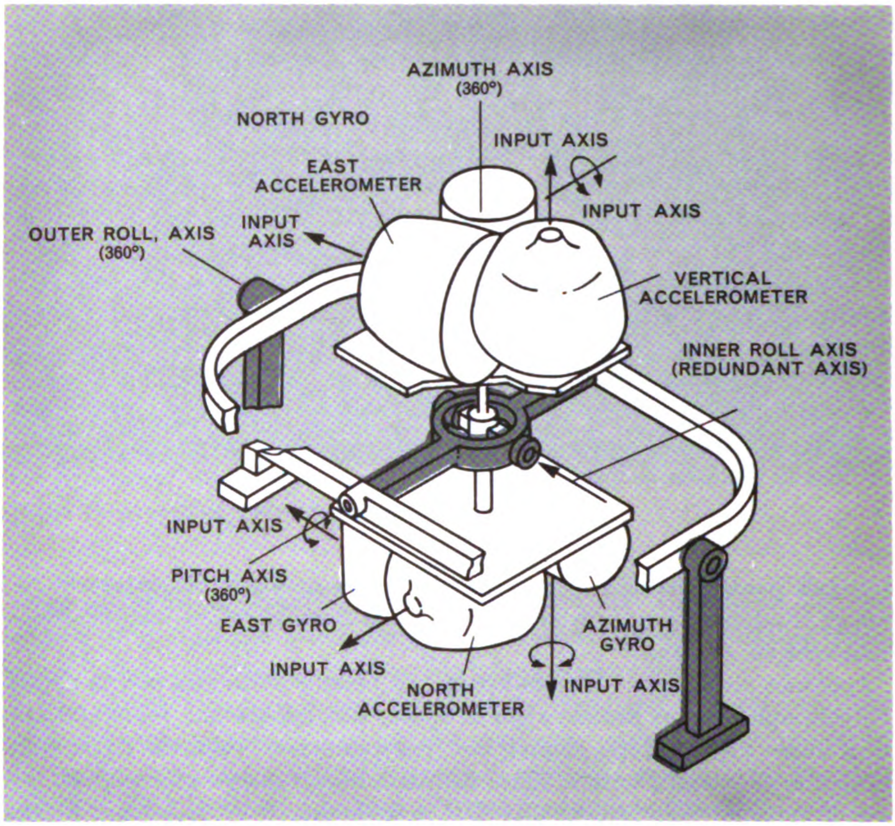


FIGURE 21. Inertial platform.

In order to compute the instantaneous position of the vehicle in flight, it is necessary to determine acceleration values in three directions, vertical, lateral, and in a to-the-target direction. A vehicle in flight can be affected by forces acting in all of these directions concurrently, hence an inertial platform, to be properly aligned, incorporates three gyroscopes. The output of three accelerometers, oriented by the stabilized platform to give accelerations in the three directions, are fed to the guidance system computer. The computer compares this data with the programmed trajectory data and generates any necessary corrective signals. The output of the accelerometers being proportional to acceleration allows the computer, by performing successive integrations of the acceleration, to calculate velocity and distance and thereby determine the necessary corrective signals to cause changes in the missile's flight path.

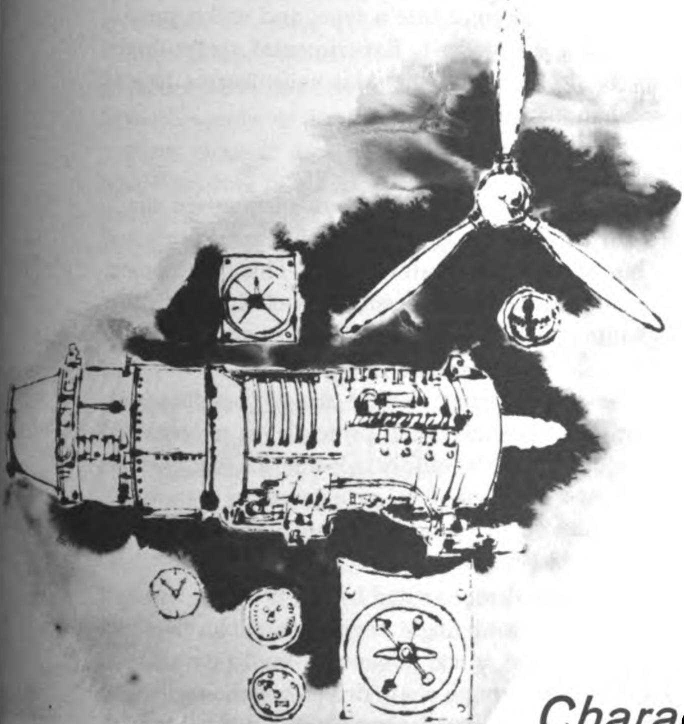
Factors Complicating Development

There are three major factors and numerous minor factors which complicated the problems faced by the engineers who developed inertial guidance systems.

The major factors are oblateness (the earth is not exactly round; it is an oblate spheroid); coriolis effect (the earth is moving under any object that moves over it); and centripetal force (in this instance, a force caused by the earth's rotation which tends to pull an object moving in a circular path toward the axis of rotation).

The minor factors include friction, shifting of weight within the vehicle, air currents, gusts, vibration, gyro drift, and extremes of temperature. These factors make every acceleration measurement subject to differing degrees of error. Before a system can be put into service, it must incorporate some means of sensing and correcting the spurious acceleration effects of all these factors. Various electronic mechanisms placed within the inertial platform help to isolate the system from such effects.


U.S. AIR FORCE



CHAPTER 4

Characteristics of MANNED AIRCRAFT

If the Air Force were to be called into combat action today, its effectiveness would still be determined in large measure by the performance of manned aircraft. This chapter is concerned with the general characteristics of these vitally important manned aircraft and the purposes for which they are built. An aircraft in the literal sense used in this chapter is any machine or craft designed to go through air when given lift by its own buoyancy, or by dynamic reaction of air particles over and about its surface.

BACKGROUND OF MODERN AIRCRAFT

According to method of propulsion, two types of manned aircraft are in operational use—propeller-driven and jet-powered to provide thrust. Hybrid

◀ The X–15 research rocket plane is dropped from its B–52 mother ship.

types, utilizing rocket accelerators, and primarily rocket-driven manned aircraft are not presented here. The first does not constitute a type, and rocket propulsion is not used in operational manned aircraft. Experimental rocket-driven aircraft exist, and the student should be aware that this constitutes a type of propulsion, although not yet combat operational.

Propeller-Driven Aircraft

Historically, propeller-driven aircraft ushered in the era of powered flight. Almost everyone is familiar with the Wright brothers' early experiments and the first successful flight of a heavier-than-air craft in 1903. This development followed much earlier experimentation with the possibilities of this and other means of propelled flight, including such devices as sails connected to winged craft and balloons, free sailing by taking advantage of benign air currents, air "oars" manipulated beneath balloons, flapping birdlike wings (ornithopters), and helicopters (Da Vinci outlined the helicopter principle as a combined flight-propulsion idea as early as the fifteenth century). While the early Greeks were familiar with the principles of steam jets, the jet principle as a means of aircraft power had to await technical developments of the twentieth century before coming to fruition during World War II.

The pusher propeller type, as initially demonstrated by the Wrights, featured a two-propeller arrangement connected to a single engine via a bicycle chain drive. A direct-drive pusher soon evolved, since advantage lay in eliminating the power losses inherent in transmission through chain drives, which were added to by their high wind resistance. Stouter, better-designed single propellers with higher speed of revolution were soon used to absorb added engine power. With this arrangement, the engine was moved to the center of the craft and the pilot no longer had to sit (or lie) to one side to balance its weight.

It seems somewhat astonishing that the pusher-type propeller arrangement now considered theoretically to be the most efficient of the propeller arrangements (chiefly because it eliminates contribution to turbulence of the airstream over the wing airfoil), almost entirely disappeared in airplane designs before World War I until development of the B–36 heavy bomber, nearly a half century after the Wrights first used it. The change to puller-type (tractor) designs was considered, however, as a great advance, and indeed, many improvements were made in this type of propulsion throughout World War I. A comparison of the aircraft designs of 1914 and 1918 will show dramatically the extent of airplane development which occurred.

The change to tractor designs came about for two reasons: to provide better balance, and less wind resistance. Early pushers suffered from faulty design, and their improperly located centers of gravity precipitated all too frequently a terrifying and uniformly disastrous flight accident—the "tailspin." During this type of tailspin the craft spun earthward tail first. By moving tail surfaces rearward, better control was assured, and by mounting the engine in the nose, inherent longitudinal stability was achieved. These factors contributed to the development of the enclosed fuselage, with pilot inside, which aided better

airflow around it. With the engine located in the nose, a tractor propeller was an obvious necessity.

Aircraft development has somewhat paralleled that of automobiles, and the advances made in nearly all of the early powerplants used in airplanes resulted from the same or similar improvements made by benefit of the automobile proving ground, as well as on designers' drafting boards. Improvements in reliability, fuel qualities, and ignition systems of automobile engines benefited aircraft as well, and provided a basis for the development of such qualities in aircraft engines as compactness and lower weight for unit measure of power.

Jet-Powered Aircraft

When, in 1944 and 1945, the first jet-propelled and rocket-propelled aircraft began to appear in the skies over Europe, thoughtful observers could not fail to appreciate the implications. These early German Messerschmitt 262's (Fig. 22) and 163's (the latter a rocket airplane with flight-time durations of 8 to 10 minutes) were the first jet-powered aircraft in aerial combat. The interesting thing about their appearance at this time was the relative lateness of it; the German capability existed for producing them by 1942 or 1943, but the Luftwaffe was unable to convince the German leadership of the importance of airpower in general and of this type of aircraft in particular. The unfortunate Luftwaffe, although an independent air arm, was closely bound to the thinking of surface warfare and to the counsels of the Wehrmacht and could never appreciably affect its own destinies.

By the spring of 1945 the dying efforts of the Luftwaffe were too little and too late, but in March and April of that year, by scraping the bottom of the barrel for fuel and pilots, it turned on the massed formations of Allied aircraft then roaming at will and gave a demonstration of what might have been. As a result of eight successful missions in those months, a bag of 58 American

FIGURE 22. German Me–262.

bombers and 11 fighters was secured, but by then the war in Europe was virtually over and these hit-and-run successes had no hope of altering the inevitable result.

The turbojet engine has but one moving part, which operates and has a sound like a giant blowtorch. The turbojet airplane engine is a gas turbine device with a phenomenal power-weight ratio as compared to the reciprocating engine. It is particularly well adapted for providing the high speeds and high operating altitudes necessary in aerial warfare. In this characteristic it surpassed in World War II, by a ratio of two or more to one, the high-speed and altitude performances of Allied aircraft.

The genesis of the jet engine extends well back into the history of aviation. Need for greater power output was evident early, and some thought was devoted to the idea of a jet-type powerplant. Although the earliest developments in Germany are obscure, it was in January 1930 that a British Royal Air Force officer named Frank Whittle applied for the first jet propulsion patent, describing it in his application as a system of compression, expansion, and heat addition to air. In April 1937, the Whittle gas turbine operated successfully on a test stand.

But on August 27, 1939, the first successful flight powered by a jet engine occurred in Germany. Both engine and aircraft were Heinkel products, an He-53b engine mounted in an He-187 airplane, the former developed and designed by the physicist Pabst von Ohain.

On August 27, 1940, a jet-propelled Italian aircraft, designed and built by Caproni, flew from Rome to Milan, a distance of 130 miles. In May of the next year, Whittle's engine was mounted and flown successfully in a special Gloster aircraft.

By July 1941, engineers of the General Electric Co. in the United States were poring over the details of the Whittle engine. With modifications, the resulting product was the I–16, the first practical jet propulsion engine in the United States. Two of these engines were mounted in a series of specially built Bell aircraft. On October 1, 1942, the first P–59 took to the air. Although its speed, range, and flight duration were short, the P–59 types demonstrated the first use of, and provided the first experience in, jet propulsion for the U.S. Air Force. By 1946, when the P–59 was scrapped, the Lockheed P–80 had already made its successful appearance, both overseas and at home, with the 1st Fighter Group.

It is interesting to note that the Lockheed product appeared initially in 1944, and was thoroughly test flown at Edwards Air Force Base, Muroc, Calif. It is a rare example of a completely new design which was conceived, designed, produced, and tested within the space of a few months. By early 1945, two models were shipped to the 305th Fighter Wing and the 1st Fighter Group in Italy. Although extensively flown, these two aircraft were never committed to actual combat.

The first P–80's utilized the I–40 jet engine, developing 4,000 pounds of static thrust at 11,500 rpm. Further development produced the J–33 engine,

which, with further modifications, was to power all successive models of the F–80 fighter. It is remarkable that no major changes were made in the design of either the aircraft or the powerplant in the several years that elapsed between the first production models and the committal of the F–80 as the first U.S. jet aircraft into actual combat at the outset of the Korean war.

Today, the special properties of the turbojet engines have caused them to dominate the combat aircraft field, and have already intruded them into the transport area. Not only fighters (Fig. 23)—including the F–100, F–101, F–102, F–104, F–105, and F–106—but also jet bombers have been developed (Fig. 24). The B–45 Tornado was followed by the B–47 Stratojet, the B–52 Stratofortress, and the B–58 Hustler.

MAJOR FUNCTIONAL TYPES OF MANNED AIRCRAFT

Depending on the type of mission a particular aircraft is intended to accomplish, some military characteristics or performance capabilities are emphasized at the expense of others when designing the craft. This accounts for the various functional types of aircraft. Appendix A lists 19 functional categories recognized and used by the U.S. Air Force, together with their characteristics and an explanation of how the various models and functional categories are lettered and numbered.

Fighters

Missions assigned to fighters fall into three categories: bomber support, combined ground-air operations, and independent fighter operations. In ground attacks, fighters use bombs, rockets, and guns in cooperation with ground forces. In independent operations, fighters perform such missions as interception of enemy bombers, searching for and destroying enemy fighters, and attacking airfields, power stations, bridges, or other special targets. No one type of fighter can accomplish all these diversified missions, especially when it must operate in all kinds of weather, day or night, as well as under all conceivable climatic and tactical conditions. As a result, fighters early became more and more specialized.

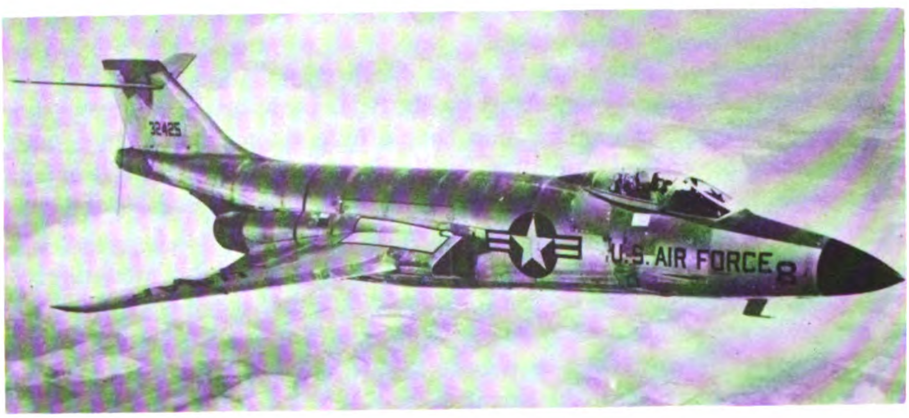
The firepower of fighters is made more effective by the use of the best fire-control system that can be developed for the type of mission. With present-day speeds and altitudes, the fighter must have a fully automatic computing and radar-ranging fire-control system for duels with other fighters or with bombers. For attacks on surface targets, some provisions must also be made in the fire-control system for strafing, dive bombing, and rocket firing.

In addition to the items noted, a fighter must also have the latest type of radio and radar equipment needed for its mission. In all-weather fighters, the whole system of radar and computing equipment used for automatically making an intercept on the enemy weighs as much as 1,500 pounds, and it occupies most of the otherwise free space in the aircraft.

In performance, speed is one of the most important characteristics for a fighter. To make a kill, a fighter must have speed so that it can catch up with

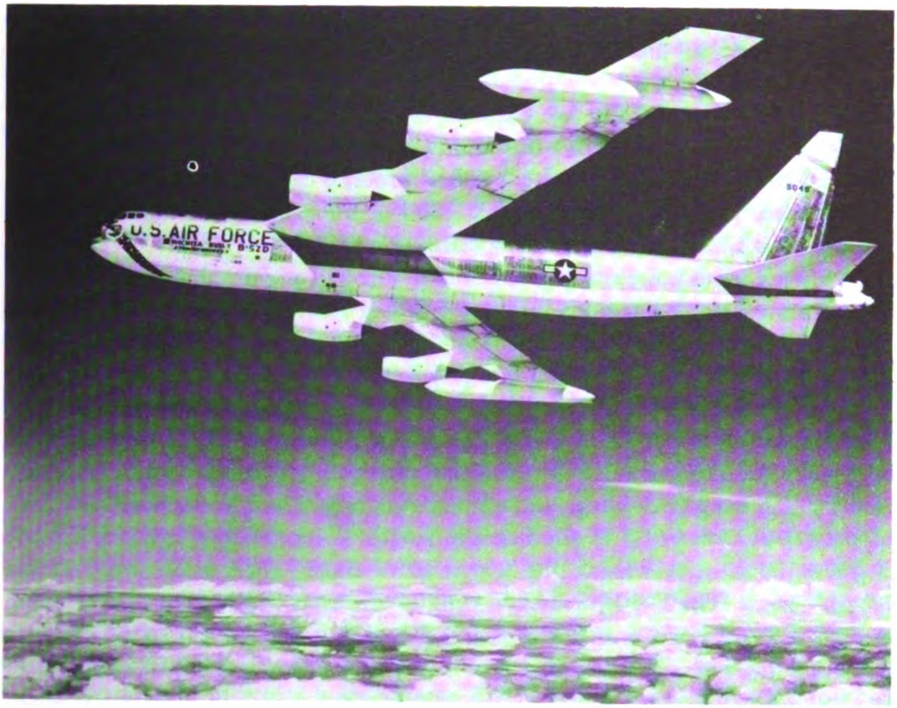
F–104 Supersonic Fighter

F–102 All-Weather Interceptor

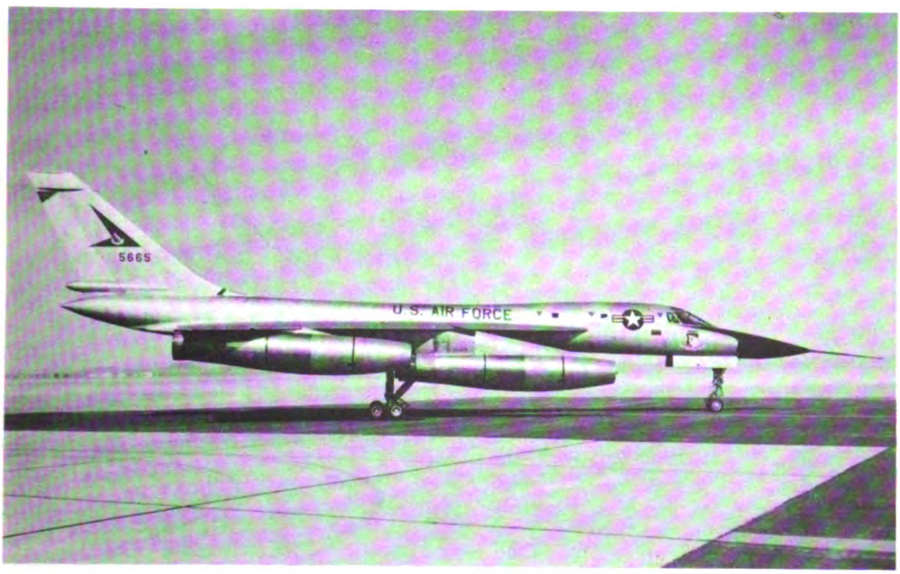


F–101 "Voodoo"

FIGURE 23. Jet fighters.



B–52D "Stratofortress"



B–58 "Hustler"

FIGURE 24. Jet bombers.

enemy bombers, which are also moving up in the speed scale. It must also have sufficient speed so that it can best enemy fighters when engaged in an air superiority mission.

Present U.S. jet fighters are capable of operating at sonic and supersonic speeds. The F–100 can exceed the speed of sound in level flight. The F–102A, powered by a turbojet engine with an afterburner, is capable of reaching into the stratosphere, and the F–104, F–105, and F–106, using advanced turbojet engines, also operate at supersonic speeds.

The tremendous power output required of turbojet engines that propel aircraft at supersonic speeds demands large amounts of fuel. The fighter consequently must sacrifice range or combat time or both to achieve these speeds, because greater fuel capacity would mean a larger, slower, and less maneuverable aircraft.

The use of a more powerful turbojet engine is not enough to insure that sufficient thrust will be produced to drive aircraft at supersonic speeds. The airframe itself must be designed for the absolute minimum of drag. It must have extremely thin sweptback wings and empennage, a relatively short wingspan (low aspect ratio), compared to the fuselage length. Some modern fighters, like the F–102A, have delta wings. The wingspan of the F–102A is 38 feet and the length 68 feet. The F–104 also has a wing of low aspect ratio. The X–5 research aircraft was designed with sweptback wings that could be varied in order to test the effects of different angles of sweepback. The rocket-propelled X–15 research aircraft also has a wing of low aspect ratio.

All the features that reduce drag seem to cause control and stability problems, not only at the low speeds of landing and takeoff but also at high speeds in the very thin air of higher altitudes. In other words, there is a conflict between the characteristics that help to produce speed and those that make the fighter a stable aiming platform. To give a fighter enough stability at high speeds, it is necessary to provide it with a highly sensitive and quick-reacting autopilot for all control axes. These autopilots add weight and make the design more complex, but they are necessary for accomplishing the mission.

Another characteristic needed in present-day fighters is ability to reach higher altitudes in order to compete with the bomber, which typically has a low wing-loading ratio (pounds of lift per square foot of wing area). Modern fighters are able to reach these high altitudes because present-day turbojet engines provide enough thrust. All "century series" (F–100 and up) fighters have ceilings above 50,000 feet.

Bombers

Throughout the development of bombardment aircraft there has been a continuous effort to increase range, speed, and bomb load. This process will undoubtedly continue until real global operations are possible. The long-term objective is an all-weather bomber capable of operating anywhere on the globe from bases within the continental limits of the United States. These objectives are close to realization with the Air Force's B–70 bomber.

In any aircraft design program a careful balance must be maintained between

what is tactically desirable and what is technically possible. Therefore, instead of setting the requirement of global range for a bomber, a more realistic operating range is established after potential launch bases are considered and an analysis is made of possible target systems and the weapon systems that will be used to attack the targets. In operational units, bombers, fighters, and fighter-bombers are now routinely refueled in the air. Figure 25 shows a KC–135 jet tanker-transport refueling a B–52 Stratofortress at high speed and high altitude. Further research in fuel and improvements in powerplants will probably increase range appreciably.

The actual combat radius of a bomber equals approximately three-eighths of its maximum range at its best cruising speed and altitude. This would mean, for example, that if a bomber is to have a 3,000-nautical-mile radius of action, it must have a range of 8,000 nautical miles. One of the chief problems in attaining long range is to develop a powerplant that will give the necessary range without sacrificing speed, altitude attainable, rate of climb, and load-carrying capacity.

In drawing up plans for a bomber, the designer must also consider the security afforded by its defensive system, its operating altitude, variation in speed, and electronic countermeasures equipment. Special emphasis is placed on automatic lightweight countermeasures devices and armament as means of protecting bombers.

As operational altitudes have become higher with the use of turboprop and turbojet power plants, the best flight path for a bomber to use in obtaining

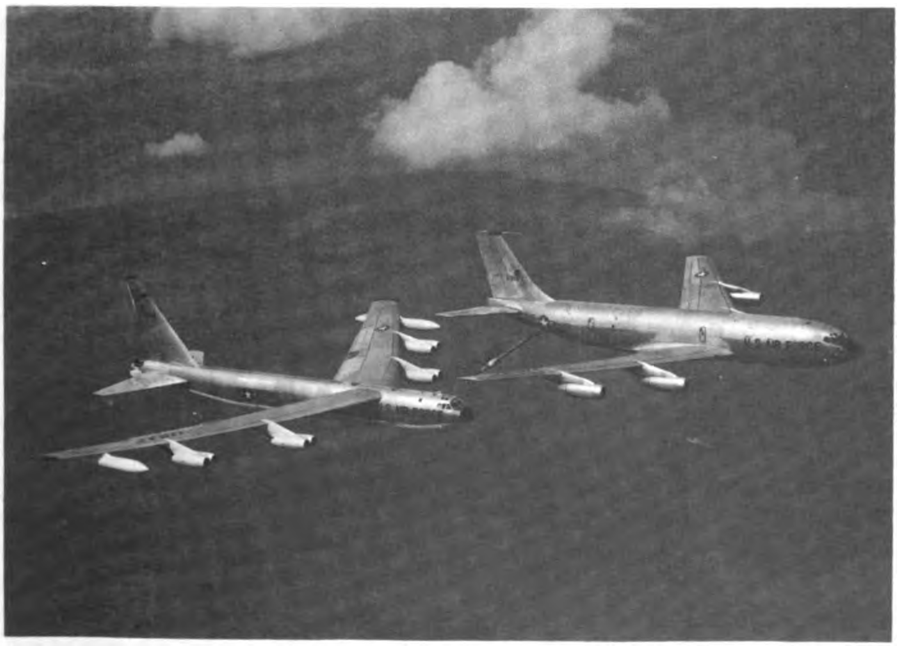


FIGURE 25. KC–135 tanker-transport refuels a B–52 at high altitude.

maximum range in withdrawing from the target area may lie at altitudes of 40,000 feet and above. There is a continuing need for more accurate radar bombing equipment so that visual bombing can be eliminated. Considerable effort must be expended to develop other equipment that will operate satisfactorily at these higher altitudes. For example, for bombing at high speeds, new bomb-bay doors and the bombs themselves have been redesigned: the B–57 bomber, for example, has a rotary bomb door.

In the bomber powered with a jet engine, just as in the fighter, the airframe designed for achieving high speeds tends to crowd most components, including fuel, into the fuselage. This fuselage cannot be expanded in cross section much beyond the cross section of a conventional bomber fuselage.

Speed is important to the bomber as well as the fighter, but to accomplish its mission the bomber must be able to reach the target. Therefore, in the bomber, some speed is usually sacrificed to attain range and weight-carrying capacity. At the same time, every attempt is made to improve the ability of the bomber to reach higher altitudes and thus give it a measure of protection against the fighter, which has a higher speed.

The B–58 Hustler, our first supersonic bomber, is designed to reach altitudes over 60,000 feet, and the B–70 Valkyrie, over 70,000 feet. In addition to great altitude, the B–70 has an advantage over fighters never before enjoyed by bombers—superior speed. This bomber was designed to give it a mach 3 speed capability.

To accomplish its mission successfully, the bomber must also provide a stable aiming platform for the bombing equipment. Stability is not quite so acute a problem in the bomber as in the fighter because of its slower speed and larger size. As bombers move into the supersonic speed range, however, stability will become a big problem for them also.

Elaborate electronic equipment is incorporated in the design of all new bombardment aircraft. This includes not only complex communications equipment but radar units and equipment for instrument landing, navigation, and other purposes. Electronic equipment adds greatly to the unit cost of bombers.

TACTICAL, MEDIUM, AND HEAVY BOMBERS.—Several types of bombers are used by the Air Force. Their designation as tactical, medium, or heavy does not necessarily refer to their weight, since the primary distinction is made by function.

The tactical bomber is a high-speed, highly maneuverable, high-altitude, limited-range aircraft. Its function is to destroy surface targets within the theater in cooperation with other air forces and with surface forces. This aircraft was designed for conducting independent bombing missions within the theater and for engaging in joint operations with ground forces in all types of weather, day or night, out to the limit of its radius of action. It should be capable of carrying a bomb load of about 15,000 pounds and of delivering bombs by visual or radar means from high altitude at the limit of its combat radius, as well as from low altitude at shorter ranges. A typical example of this class of bomber is the B–66.

The medium bomber is a high-speed, high-altitude, medium-range aircraft. Its tactical mission is to bomb surface targets over an operating radius of about 1,750 nautical miles. It should be the workhorse in bomber operations, since it carries all types of bombs and is capable of sustained operation from bases near enemy targets.

The heavy bomber is a high-speed, high-altitude, long-range aircraft. It should have a radius of action that is almost global. This large operating radius is achieved in some bombers by aerial refueling, which extends ranges from bases in the United States to points anywhere in the world. The B–70 is designed for almost global operating radius without refueling.

Development of the B–70.—Acceptance of the weapon system concept brought about a readjustment of design programing. In the new concept, the "black boxes" which control the ultimate utilization of the vehicle are developed first, and then the vehicle itself is designed to meet the demands of the weapon. The programing of the B–70 is an excellent example of weapon system design.

The aircraft specifically designed to replace the subsonic B–52 heavy bomber is the B–70 Valkyrie. The B–70 was designed to cruise in the thin air at 70,000 feet at a speed of mach 3, where the air molecules scrubbing along the steel-clad fuselage will heat it to around 550° F. The B–70 bomber represents significant aerodynamic developments in three directions: speed, range, and altitude.

The canard-configured B–70 (with stabilizers and elevators near the nose and a huge delta wing, one-sixth acre in area) looks more like a missile than an airplane. Its capability is to reach any point on earth in 5 hours. Later aircraft, using these same aerodynamic principles and being properly powered, may go to mach 4, mach 6, or even mach 10. A mach 16 engine design has a patent already pending.

With a range of approximately 6,100 nautical miles, the B–70 is designed to travel this entire distance at supersonic speeds without refueling, while operating above 70,000 feet. No present interceptor aircraft can survive the thermal environment at such speeds and altitudes.

Instead of a single warhead, the big bomb bays of the B–70 are designed to carry multiple loads of any bombs now on the shelf or new weapons not yet designed but for which there is a requirement. The Valkyrie is completely flexible. Although the bomb load will be its primary weapon, it will also be able to carry an air-launched ballistic missile such as improved versions of the Skybolt. The hypersonic Skybolt, traveling at mach 5 or better, can be launched 1,000 miles from the target with a high degree of accuracy.

Although the Valkyrie is limited to operation within the earth's atmosphere, it could contribute considerably to this country's space program. This aircraft can be an ideal substitute for the first stage of a space rocket. At 70,000 feet and a speed of mach 3, the B-70 has the boost equivalent of an Atlas launched from the earth. An Atlas-type booster can be used but once; a B–70 booster system, over and over.

Besides being able to do many things that a missile cannot, manned aircraft such as the B–70 are tangible proof of the state of readiness of the United States to retaliate against aggression. The complexities and capabilities of the airplane provide a constant challenge to keep crews and support personnel alert. A psychological weapon with a great impact, the airplane has performance and versatility that all can see—our own people, our allies, and the enemy.

The B–70 has still other potentialities. It is a big airplane despite the fact that it occupies less floorspace in the hanger than the B-52 and operates from the same runways. With relatively little modification, it can be made into a mach 3 transport capable of airlifting 60 people to any spot on the globe within 5 hours. With such an air vehicle, for example, delivery of six of the Army's Honest John missiles with their crews anywhere in the world is possible.

Finally, the basic design features of the B–70, with the crew sitting far ahead of the engines, makes it relatively simple for engineers to program the airplane for nuclear propulsion plants.

Transports

Before World War II, transport aircraft were used only for hauling passengers and cargo. They were thought to have no tactical value. Therefore, in order to save money, the Air Force bought commercial types of transports for which development expenses had already been absorbed by the aircraft industry. As the war developed, transports were put to many different uses, such as moving and dropping troops and supplies, and carrying heavy equipment for tactical operations. It soon became apparent that specially designed transports were needed. Military characteristics were therefore prepared, calling for transport aircraft that could move airborne units and paratroops, wounded personnel, supplies for air and ground units in the theaters, and personnel, equipment, and supplies going from the zone of interior to the theaters.

Millions of dollars and years of effort were expended to give transports higher ceilings, better rates of climb, more speed and range, and more payload capacity. All these performance characteristics have become more difficult to attain as aircraft have become larger and heavier. Therefore powerplants have been improved, turbojet engines used in many cases, and the wing and fuselage surfaces redesigned to decrease drag at cruising speeds.

Air Force transport aircraft are of four classes: heavy, medium, assault, and light.

The heavy transport is a very large aircraft used mainly to supply rear areas. A typical example of the heavy transport is the C–130 Hercules. The C–133 Globemaster III is also a long-range cargo carrier. The Air Force also has a few heavy jet transports, and a large fleet of all-jet Stratotankers, which can also be used for carrying high-priority cargo.

The medium transport is used for most theater air transport missions.

The assault transport is used to carry troops, weapons, and supplies in making an airborne assault on enemy positions or in establishing airheads in enemy territory. The C–123 is an assault transport.

The light transport is used for moving personnel and cargo when large airfields are not available.

Transport aircraft do not carry armament. They are designed for carrying the largest cargo or troop loads, for attaining maximum range, and for providing comfort for the crew instead of for attaining very high speeds, for carrying defensive equipment, or for maneuverability.

In airborne operations in the past, conventional transport aircraft were supplemented by gliders. These gliders possessed several inherent disadvantages: they were vulnerable to enemy defenses, could carry only a certain size and a certain quantity of material, and required comparatively large landing areas. An assault transport has been designed to replace the glider.

Present assault aircraft incorporate a number of novel features that have been evolved from a study of operational requirements. In the design, utility takes precedence over performance. The result is an aircraft that is expected to provide a stimulus to the development of commercial cargo aircraft, as well as military aircraft. The assault aircraft is rugged, can be loaded much more simply and quickly than other transports, and has a low operating cost. Some of its other good features are straight-in-rear loading with integral controllable ramps, elimination of all but the most vital radio equipment, and a very short and compact landing gear. For operations requiring more elaborate radar, radio, and navigational equipment, portable stations are being developed for the radio operator and the navigator. These stations can be readily inserted in the aircraft and coupled into its communication system. The portable stations will permit the aircraft to operate independently or as a lead aircraft in formations.

Reconnaissance Aircraft

To enable them to operate individually to obtain intelligence on which bomber and fighter operations can be based, reconnaissance aircraft tend to be designed for better performance than either fighters or bombers.

There is some controversy over whether it is better to build a separate type of high-performance reconnaissance aircraft at the tremendous cost involved, or to modify existing types of fighters and bombers to meet reconnaissance requirements, as was done during World War II. An example of a reconnaissance and weather observation aircraft built specifically for these purposes is the U–2 (Fig.

FIGURE 26. The U–2 aircraft is an upper air research and weather reconnaissance plane.

26). However, the trend at present seems to be to convert bombers into reconnaissance aircraft by attaching pods containing whatever reconnaissance equipment is necessary for a particular mission. These pods can be easily fitted into the bomb bay, thus rapidly converting the bomber for any kind of reconnaissance mission without sacrificing any of its capability for carrying out subsequent bombing missions.

It is still true, as it was during World War II, that a reconnaissance aircraft can be produced simply by reducing the armament and other loads of a combat aircraft or by eliminating them completely. After the conversion, the aircraft is faster and consequently is better able to elude fighters.

Helicopters

One of the most active fields of aircraft development is helicopters. There are two distinct classes of helicopters: liaison helicopters and combination cargo and rescue transports.

Military characteristics for helicopters are established and acted upon in the same manner as those for other aircraft. Helicopters such as the H–19 are be-

FIGURE 27. H–19 Helicopter equipped with amphibious landing gear.

coming increasingly important for air rescue and for making rapid short-range movements of troops and equipment to critical areas (Fig. 27). They are also used to establish beachheads across rivers or other barriers. They do not require prepared airfields for operations.

The helicopter can fly low and slow in any direction horizontally or vertically and at reasonable height and speed. It can stand still in the air, revolve on its axis, hop hedges or mountains, taxi on the ground, and land in a backyard,

on a roof, on water, or on a ship's deck. Heavy-lift helicopters such as the H–21 can transport fully equipped troops or heavy cargo.

Control is supplied by a small upright rotor on the sides of the tail of single-rotor helicopters. This is a torque-counteracting device which prevents the helicopter's body from spinning in the opposite direction to that of the revolving rotors. This small tail rotor also aids in directional control by swinging the fuselage about to point in the direction desired. The tendency for the whole helicopter to travel sidewise in the opposite direction to the tail rotor thrust is counteracted by rigging the helicopter with the rotor tip path plane slightly tilted.

The capability of nearly vertical ascent and descent permits the helicopter to fly into and out of areas inaccessible to ordinary aircraft and to perform missions not previously possible by any aircraft. Probably the most notable of these duties is rescue work over almost any terrain. For combat zone missions, the helicopter came into its own in Korea, where several years of valuable performance in many vital and varied tasks under difficult conditions are credited to it. At least a thousand United Nations individuals, including those forced down in water and in mountainous terrain, were saved in helicopter rescue operations in this war alone.

Besides rescue missions, the helicopter may be utilized for observation and limited reconnaissance missions. It can observe enemy areas, inspect proposed sites for airbases, landing fields, or radar sites, and make close inspection of terrain for lost aircraft. It can transport airborne raiding parties, and many, with development of suitable load-carrying characteristics, tend to take a larger and larger part in airborne airhead operations. Duties of a courier and administrative nature may also be accomplished.

Despite all the helicopter can do now and all it promises to do in the future, it is not without some major faults and disadvantages. Its range, altitude, and speed are limited, but even the limiting factor of altitude can be overcome by improvements in design, as indicated by the turbine-powered H–43B Huskie. The technical development of the helicopter has barely begun.

DESIGN REQUIREMENTS COMMON TO ALL TYPES OF AIRCRAFT

In addition to the military characteristics needed for a particular type of aircraft because of its mission, there are other characteristics necessary to all types of military aircraft. These characteristics must be carefully considered in establishing the requirements, as well as in all parts of the research and development cycle.

Structural Soundness

In many instances, one of the biggest problems in the structural design of the aircraft is the increase in weight that occurs without a corresponding increase in space. This increase in weight is caused by a number of factors: greater fuel

consumption of the jet engine; the heavier structure necessary to withstand the increased airloads at high speeds; the complex and heavy fire control equipment required for effective combat at high speeds and high altitudes; and additional provisions for the safety, comfort, and survival of the crew as the combat speeds and altitudes go up. When guided missiles are to be fired from aircraft, their inclusion will increase the total weight of the aircraft even more. All this additional weight must be taken care of at the same time that increase in size, hence drag, is kept to a minimum.

Structural problems are posed by the very thin sweptback wings used on many aircraft and by the necessity for designing engines within reasonable size limits. To give thin wings of any configuration the necessary structural strength, the skin must be made thicker. During World War II the skin of an aircraft wing or fuselage was seldom more than one-sixteenth of an inch thick. Today, skin thickness on some models is so great the wing is almost solid.

The aircraft structure should also be designed so that it can withstand a reasonable amount of battle damage. While this is becoming increasingly difficult as aircraft become faster and more complex, the increases in structural strength required to meet the dynamic airloads and temperature of supersonic flight may tend to reduce the effect of battle damage.

Stability and Control

That property which causes an aircraft to return to its original flight attitude after its equilibrium is disturbed is known as stability. In supersonic aircraft stability and control problems occur at both ends of the speed scale and are requiring more and more of the designer's attention.

Control pertains to the response of the aircraft to the pilot's actions. The aircraft must be controllable when flying under all possible combinations of operational loading, and must be well within the capability of the average pilot.

The Air Force regards an aircraft as unsatisfactory if it gives evidence of poor control just before landing or just after takeoff, if the pilot must continually exert himself to maintain straight and level flight, or if an extreme degree of skill is required to control the aircraft when one or more engines become inoperative. The procurement of such an aircraft would not be justified in view of probable operational losses and the loss of confidence that it would create among aircrews.

Provisions for Comfort and Safety

As aircraft become more complex, they make greater demands on the physical and mental abilities of the crews (Fig. 28). The designer must recognize the definite limits to human endurance and ability lest the very best aircraft from the mechanical, aerodynamic, or tactical standpoint fall short of the performance expected. Further, although the aircraft may operate within the range of human capabilities, a lack of consideration for the crew's safety and comfort may result in an unwarranted reduction of efficiency. Safety provisions may range from allowing space for crewmembers to stretch their legs to providing armorplate protection or equipping jet fighters with ejection seats.

FIGURE 28. Man in full-pressure suit attempting to manipulate controls in a study of decelerative forces on the centrifuge at the Wright Air Development Division.

Crew safety is continually emphasized by the Air Force. No design is accepted if indications are that the aircraft has good operational characteristics at the expense of crew safety. If attention is given to the safety, comfort, and efficiency of the crew early in the design stage, a solution to these problems can usually be arrived at with a minimum penalty in performance.

From studies made at the Aerospace Medical Laboratory at Wright-Patterson Air Force Base, it was found that a large proportion of aircraft accidents can be eliminated if the cockpit is designed with the pilot in mind. Good design also reduces the amount of concentration required to fly the airplane. In the high-speed aircraft it is especially important that the pilot's efficiency be increased and his workload be reduced.

Standardizing cockpits has gone a long way toward improving a pilot's

efficiency. In a standardized cockpit or crew station, all dials, levers, and switches are placed in the same position in different aircraft. With such an arrangement, the pilot or crewman can perform his duties more efficiently. He can change from one aircraft to another and operate with the highest proficiency after only a small amount of time spent in familiarizing himself with the aircraft. While it is impossible to build one cockpit that will fit all aircraft, a standard cockpit can be designed for a fighter, another for a bomber, and still another for a transport. The main reason for standardizing cockpits is to achieve safety in flight. An efficient cockpit is a safe one.

Anyone who has sat in the cockpit of a fighter for 4 hours or of a bomber for a much longer period knows how petty annoyances build up. It is possible to make a cockpit safer simply by making it more comfortable and thus reducing pilot fatigue. In aircraft that travel two or three times as fast as the speed of sound, the possibility of overheating the crew and of weakening the structure is very real. The heat generated by the friction of the air on the skin of the aircraft at supersonic speeds creates problems that may be most difficult to solve. Even in aircraft traveling at speeds close to that of sound, it is already necessary to provide some refrigeration for the cockpit.

As speeds have increased, the Air Force has been faced with the necessity of providing some mechanical means for the pilot to escape from the aircraft. Seats have been developed that can be ejected from the aircraft with enough velocity to clear the airplane without subjecting the occupant to dangerously high accelerations.

The ejection seat is essentially a sturdy pilot's seat equipped with foot and arm rests, and a special headrest. The armrests support a large portion of the force that would normally be transferred to the spine. The headrest prevents injury to the neck during ejection.

The ejection seat solves the problem of escape at speeds ranging from 350 to 435 knots, and there have been a few instances of successful ejections at low supersonic speeds. But at sonic and supersonic speeds, the effects of deceleration and windblast become very serious. Designers have developed several versions of capsules and portions of aircraft that will separate in an emergency and carry the aircrew safely, without tumbling, to an altitude and degree of speed where the descent can be completed by parachute. Other designers call for the aircrew to remain in the capsule or portion of the aircraft all the way down.

Another hazard to aircrews is the rarefied atmosphere at the high altitude at which aircraft now fly. Operational altitudes of aircraft have been constantly increasing. During World War I, aircraft usually flew at altitudes under 10,000 feet. In World War II, operations were conducted at altitudes as high as 38,000 feet. The X–1A research aircraft exceeded an altitude of 90,000 feet, and the F–104 flew even higher. The X–15 has been designed to climb to an altitude of over 50 miles.

There are many reasons why it is necessary to increase the ceiling of aircraft. From an operational viewpoint, high altitudes are desirable because they reduce

the hazards of air defense, fire, weather, and uneven terrain and because they can take advantage of high winds. Also, jet engines operate with most fuel economy at high altitudes.

Man normally lives at or near sea level. He experiences mental and physical difficulty after prolonged periods at altitudes of 10,000 feet. The higher he goes, the less efficient he becomes. Finally, if he remains at or above 23,000 feet for any length of time, he is almost certain to perish. It is therefore necessary for designers to approximate the atmosphere of lower altitudes if high-altitude flight is to be possible.

The oxygen systems used in Air Force aircraft are of the demand or the pressure-demand type, which means that oxygen flow and pressure are automatically adjusted to keep the supply of oxygen in the blood at a normal level. This adjustment continues up to an altitude of 34,000 feet, at which height pure oxygen must be supplied. When man flies above this altitude, even though he breathes pure oxygen, the oxygen content of the blood gradually decreases until at 40,000 feet it is about equal to what it is at 10,000 feet where air is breathed. Altitudes from 30,000 to 40,000 feet may be attained safely only if the mask fits closely and no oxygen leaks. Above 40,000 feet pure oxygen must be forced into the lungs under pressure. This may be done either by pressurizing the cockpit or by using pressure-breathing oxygen equipment.

One of the disadvantages of pressure-breathing equipment is that it requires breathing against a force, which becomes tiring after a time. Pressurizing the cockpit does not solve all high-altitude problems. It does not, for example, eliminate the danger of explosive decompression. This takes place when the pressure inside the cockpit drops instantly to that of the outside air as a result of the failure of some part of the structure. Pressurizing the cockpit adds weight to the aircraft.

Ease of Maintenance

Because maintenance is frequently required in combat and must often be performed under adverse conditions, serious attention must be given, in the design stage, to rapid and simple servicing and repair. The special tools and equipment required for servicing should be held to a minimum. Such a policy not only promotes standardization of equipment but also simplifies supply.

Ice accumulation, thermal contraction and expansion, faulty lubrication, corrosion, and fungi can make aircraft unserviceable. An aircraft and its equipment and accessories must therefore be designed to function satisfactorily under all climatic conditions and throughout an atmospheric temperature range of $-65°$ to $+165°$ F. The possibilities of flying when shock acceleration, vibration, and explosive vapor conditions in the fuel tank are present must also be considered.

Ease of Production and Procurement

If an aircraft is to be suitable for military use, it must be a technically superior product that is relatively low in cost and that can be quickly produced in quantity. Materials must be available so that in limited wars production

can be increased rapidly with the smallest amount of drain on the national economy.

COMMUNICATIONS SYSTEMS

To be effective in aerospace warfare, aerospace craft must have not only the capability of operating with suitable loads in the air ocean, but be able to operate precisely in time and place as a coordinated segment of aerospace power. Collectively, the communications systems of aircraft constitute one of three broad auxiliary operational systems designed to permit such effective aerial operations. The second and third of these broad systems, instrumentation, and navigation-target attack, are presented subsequently.

The Necessity for Aerial Communications

Communications for aerial operations has two uses: to command and to control. As in all military operations, the squadron leader must issue orders to the airplanes of his squadron, and the group leader to squadrons in his group. The higher commander back at the base may have to issue orders to his group in flight. This necessity for command communications exists in every military unit, and the need is more, not less, when units are engaged in aerial warfare.

Even when not engaged in aerial warfare, aircraft need good communications for control purposes—information to aid in flying and navigation of the aircraft. One of the most common forms of this is weather information. Knowledge of weather conditions that exist, and forecasts of what is expected in the near future, will always be of prime importance to those who fly. Weather conditions can change rapidly and information about the changes must be sent to the flying airplane. The airplane, unlike some of man's inventions, makes him more dependent than ever on his knowledge of weather.

Navigation and traffic control information must also be related to the pilot. This would include such information as his position as determined by direction finding stations, positions of other aircraft, and landing instructions—including instrument landing information. Such information must reach the pilot quickly and distinctly to be of use.

A good communications system for military aircraft must do many things at many times. To be useful, a communications system must have the following attributes: reliability, speed, security, flexibility, simplicity, and economy. How closely the present system comes to fulfilling these requirements is a good measure of its usefulness.

Aircraft communications systems are of two basic types—visual and electronic. Visual systems were the only systems that could be employed in the early days of aviation. Later, radio systems were employed. As aircraft improved, so did radio, and today it is the primary communications system for aircraft.

Visual systems of communications for aircraft, although limited in application, still have important uses. The visual system consists of hand signaling, aircraft maneuvering, light signaling, flares, and panels. Runway markers, wind tees, and similar ground markers are not usually considered part of a communi-

cations system, but are in reality methods of signaling information, such as position and windspeeds, to pilots.

Radio communications systems in aircraft use are of two general types: command and liaison. Generally speaking, the command system is used for very short distance communications and the liaison system for long distances. All Air Force aircraft carry a command system, but only the larger long range airplanes have a liaison system installed.

One of the primary needs for communications on aircraft exists among the crew members. This system is known as the intercom, or intercommunications system. It is a simple telephone hookup, so arranged that transmission from any station in an aircraft can be heard on all other stations. Headsets and microphones are at each station, and a control box is provided for them to be plugged into. The intercom system also provides a listening post or transmission post for each of the radio sets in the communications system.

Command System

The primary purpose of the command set is to provide communications between aircraft and between aircraft and ground stations in the immediate vicinity. This is accomplished by using transmitter and receivers in the UHF and VHF (ultra high frequency and very high frequency) wavebands. The radio waves transmitted by these sets tend to travel in a straight line, as does light, and are not affected greatly by outside interference of static. The sets are good for 30 to 100 or more miles, depending on height and position. The command system is primarily a pilot's radio. It is operated by simply selecting each desired frequency.

Liaison System

In the past, aircraft radio has not been required to transmit over extreme distances, but such long-range aircraft as the B–52 and B–70 introduced a requirement for liaison communications as far as halfway round the world.

Frequencies used in liaison transmission lie in the very low frequency (VLF), low frequency (LF), medium frequency (MF), and high frequency (HF) bands. These wave frequencies are useful because they are reflected by ionized gas layers in the ionosphere (upper atmosphere) back to the earth's surface. Thus these waves travel much farther around the earth's surface than higher frequency waves, which penetrate the ionosphere. This transmission requires, however, a different frequency for each distance, time of day, and position of the earth's surface.

Liaison radio sets are used for both voice and CW (code sent by use of a telegraph key). CW permits transmission over longer distances and under more adverse static conditions than voice, but requires a trained radio operator.

On modern aircraft, radio antennas present the designers with difficult problems. On low-speed aircraft it is sufficient that they be short external posts, with wires stretched between them, or wires stretched between such parts as tail and wing tips, or simply a long trailing wire behind the aircraft. With

the cleanness required by modern high-speed designs, these arrangements are impossible. Antennas must be enclosed within the body of the aircraft, or a part of an aircraft such as the wingtip. This works well for the command set, but will require more development before it is completely satisfactory for liaison transmitting.

INSTRUMENTATION SYSTEMS

These constitute the second of the three broadly defined auxiliary operational systems of aircraft which are necessary for effective aerial operations. To the uninitiated, the cockpit of a modern high-speed aircraft presents a bewildering and confusing maze of dial faces, levers, and switches (Fig. 29). To the trained

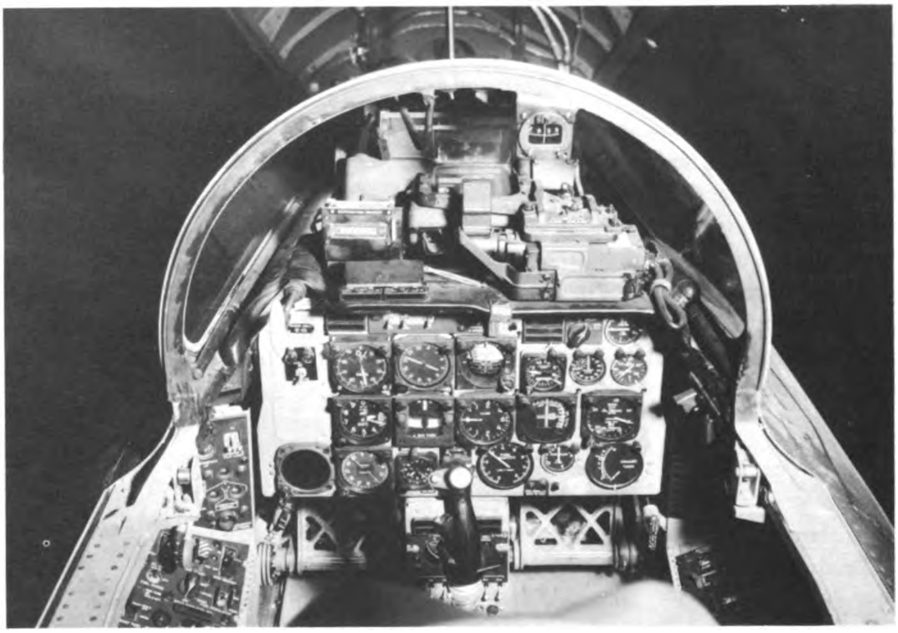


FIGURE 29. F–100D cockpit.

pilot, however, these are the extension of his senses that allow him to control this large, powerful, and complex machine. The student pilot is slowly and thoroughly initiated into their purposes until their use becomes second nature.

Instrumentation in aircraft will vary with the type and performance characteristics of the aircraft. Simple aircraft, such as small liaison aircraft and many light civilian airplanes, have instruments to show only speed, altitude, fuel, oil pressure, and engine temperature. Larger types of aircraft whose operation may require that they be flown by instruments alone require more instruments. Flight by instruments alone was accomplished at first with surprisingly few instruments, and this is still possible in an emergency. Many

more instruments have been added through the years to make instrument flight easier and more accurate.

There are two basic types of instruments: direct reading and remote indicating. The first, reading instruments, record within the instrument case and have a dial or indicator for presentation in, or at least close to the case. In the remote-indicating instruments, the recording device is at the place where the measurement is to be taken, while the dial or indicator is in the cockpit. An electrical circuit connects the two and causes the indicator to show what the recording mechanism is measuring. In modern practice, remote-indicating instruments are always used where measurements must be taken at a distance or where the routing of fuel, oil, or hydraulic systems through the cockpit would create a hazard.

The basic instruments used to operate the airplane can be divided into three classifications: the flight instruments, the engine instruments, and the miscellaneous aircraft system instruments. The flight instruments tell the pilot the height, speed, direction, and altitude of his airplane. The engine instruments tell the operating condition and power output of the engines. Other indicators give the necessary information about the operation of the aircraft's fuel, electric, and hydraulic systems.

Flight Instruments

Instruments that the pilots use most, especially during instrument flight, are called the basic flight instruments. These include the compasses, the instruments of the pitot-static system, and the gyro instruments. Of these, the oldest and most familiar is the compass. Although almost all aircraft today carry refinements on the early compasses that are known by such names as the earth-inductor compass and flux gate compass, they all carry a simple magnetic compass similar to those long used by mariners. The purpose of all these compasses is to indicate the heading of the aircraft with respect to the magnetic North Pole.

The instruments of the pitot-static system take their names from a specially constructed tube, called the pitot-static tube, protruding into the airstream. This tube, which is in reality two tubes in one, conducts the pressure of still air (static pressure) and the dynamic pressure of air rammed into the tube by the aircraft's motion, into the instrument. The pitot-static instrument readings derive from relative differences in the static and dynamic pressures. The airspeed indicator shows the aircraft's speed through the air. Also, owing to the fact that the static air pressure decreases with altitude, the altimeter indicates changes in altitude. From changes in static pressure the rate-of-climb indicator reflects the rate of ascent or descent.

All of the gyro instruments utilize the phenomenon of stability in space peculiar to a spinning gyro. The gyro always attempts to maintain its axis of spin in the same plane, and any movement of the aircraft which tends to move the positions of the gyros within the instrument can be recorded as a change in the aircraft's attitude. The first of these instruments to be invented was the bank-and-turn indicator. This instrument measures the aircraft's rate of making a turn and whether or not it is skidding in the turn. The turn indicator shows

the number of degrees that the aircraft has turned from the preset heading. Perhaps the most complex of the gyro instruments is the artificial horizon. From the position of the line that represents the horizon, the pilot can determine whether the wings are level and if the airplane is in a climbing or diving attitude.

By using a turn indicator and an artificial horizon in conjunction with electrical or hydraulic systems, engineers have constructed what are known as autopilots. Any variations from the straight and level, as recorded by the gyro instruments, are used to accentuate booster units, which activate the airplane's controls to return it to normal flight.

The instruments mentioned in the preceding paragraphs are those used on all aircraft that are equipped for instrument flying. They are the same on all aircraft with one exception. On modern high-speed fighters a machmeter has been added. This is used on aircraft that can approach or exceed the speed of sound and gives the pilot an indication of his speed in relation to the speed of sound.

Engine Instruments

The engine instruments enable the pilot to know how the engines are functioning. This in turn enables him to get the best performance from the engine, as well as to detect malfunctions.

The engine instruments give the pilot indications of such things as the quantity of oil remaining, the power output of each engine, and the temperature of the engine. Since so many of these instruments for conventional reciprocating engines are self-explanatory, some of them are listed below:

Oil quantity gage
Oil pressure gage
Oil temperature gage
Fuel pressure gage
Cylinder-head temperature gage

Some of the instruments used to measure the power output of the engine are not so self-explanatory. The tachometer measures the revolutions per minute of the engine. The manifold pressure gage measures the pressure of the air entering the engine's combustion system.

It should be remembered that for multi-engined aircraft there must be one of each of these instruments for each engine. For ease of reading, all like gages are usually placed in a line. If all of the pointers are aligned, then the engines are functioning properly. In addition to the instruments mentioned above, numerous others are employed on large or complex engine installations.

The engine instruments used in turbojet engines are usually fewer in number than in reciprocating engines. The main ones are the tachometer, fuel-flow meter, and the exhaust gas temperature meter. The tachometer is used as the measure of power output in percent of maximum power (although in recent aircraft models the tachometer is not an exact measure of power). The amount

of fuel being burned per minute is shown on the fuel-flow meter. Temperature of the exhaust gases measured in the tailpipe is indicative of the engine's proper functioning.

Miscellaneous Instruments

A number of miscellaneous instruments are used to record functioning of the aircraft's fuel, electric power, and hydraulic systems. Of these, those in the fuel system are the simplest, at least as far as numbers of types go. Most aircraft have a fuel quantity gage to measure the fuel remaining in each tank. On turbojet fighter aircraft, this takes the form of an elaborate light system to warn when tanks are empty. In turbojet fighters the fuel-flow meter is often connected to a totalizer that shows the total fuel remaining in the aircraft.

The electrical power used in a large aircraft will often approximate the power consumption of a small village. To gage this power system, a voltmeter to measure line voltage and an ammeter to measure the current output of each generator are installed. Usually a generator is installed with each engine.

On the majority of Air Force aircraft, such equipment as brakes, flaps, landing gear, cowl flaps, bomb bay doors, and dive brakes are operated by hydraulic pressure. Two instruments are needed to monitor the hydraulic system: the hydraulic pressure gage and the hydraulic fluid quantity gage. When emergency systems are installed in the hydraulic system, suitable gages are installed to show the pressures in them. In conjunction with the hydraulic system are instruments or indicators to show the position of each piece of equipment operated, such as landing gear position indicators.

Only a representative number of aircraft instruments have been discussed in this section. The number and installation will vary with the need in each type of aircraft. As oxygen systems and cabin pressurization systems are added to aircraft, the number of instruments grows. Each helps the pilot to take the measure of a condition that he cannot determine with his own senses, or to obtain information from a part of the aircraft that is otherwise inaccessible to him.

NAVIGATION AND TARGET ATTACK SYSTEMS

These constitute the last of the broadly defined auxiliary operational systems of aircraft which are necessary for effective aerial operations. Distances vary considerably as aircraft fly typical combat missions from airbase to target or target area, and return to airbase. It may be necessary to move only 10 or 15 miles to reach the target; or it may be necessary to travel 3,000 to 4,000 miles to a target and back. Today, flights across the Pacific and Atlantic Oceans and across the North American continent are daily occurrences, yet such flights are much less routine than may be immediately apparent. That such travel is sometimes performed at relatively slow or high speeds; in darkness or rain, snow, and ice; and at altitudes ranging from near sea level to above 40,000 feet makes it imperative that navigation be as accurate and timesaving as possible.

The Navigational Problem and Methods of Solution

Navigation through the air ocean involves essentially determining a desired track and then following it as closely as possible. This is a fairly simple operation, but one which requires special equipment in the aircraft. Equipment and systems which are installed in the aircraft are treated in this section.

Early in the developmental history of aircraft, navigation was crude, chiefly on a hit-or-miss basis. There were no aeronautical charts in existence which presented specialized information useful to pilots. With the introduction of aerial charts came a series of ground aids, such as rotating light beacons delineating airways, airfield marker lights, and the like. Shortly after these innovations, radio range locators were built by the Government, and with the aid of crude early aircraft radio sets, pilots could hear the "dits" and "dahs" of station identification and orientation signals. By flying the beam, or working an orientation problem, pilots were able to navigate from station to station or to locate themselves in relation to one station.

Navigation in aerial warfare is usually aided by some type of electronic equipment. It may be the simplest radio transmitter and receiver. For instance, when within the range of a homing direction-finding station, such as on most Air Force bases and large civil airports, an aircraft may request a homing, and secure in return a course to fly to the station, or to any desired destination.

Another simple electronic device used in almost all Air Force aircraft is the radio compass. This comprises a radio receiver and an automatic direction-finder loop mounted in or on the airplane. When a radio station is tuned on the receiver, a pointer located on the instrument panel will point toward the transmitting station. Without the automatic feature, the compass may be operated manually and an orientation made by the use of signal nulls (a minimum signal).

Certain Air Force aircraft, notably medium and heavy bombers and radar-equipped fighters, carry electronic equipment designed for other primary purposes which may be employed in navigation. In the case of the bombers this is the radar used in bombing. With this radar, it is possible to identify a city, lake, river, or other landmark on the ground and determine its exact range and bearing. This information gives the location of the aircraft. The ground speed and drift of the aircraft can be determined from the rate and direction at which objects move across the radarscope.

The radar used in bombing has a computer into which the navigator places information about groundspeed, course, and drift. This information is obtained from the radarscope, the airspeed indicator, and other sources. The computer then continuously gives the position of the aircraft in terms of latitude and longitude.

One type of navigation equipment is the "Rebecca-Eureka." Rebecca is the code name for a transmitter-receiver located in an airplane, and Eureka is the ground beacon. Transmission of a pulse of energy by Rebecca causes Eureka to answer, and this return is displayed as a "blip" on the aircraft scope. By its position on the scope, the beacon is located. This system is effective from 30 to

75 miles, depending upon the distance and power used in the beacon. It is used chiefly for navigating toward such localized areas as airborne troop drop zones, or between aircraft in the air.

Shoran is another system closely related to both navigation and bombing. Primarily developed as a navigation device, "shoran" is an abbreviation for the term "short-range navigation." For bombing, it is one of the most accurate blind methods known. Its use in this connection will be discussed later. As an aid to airplane navigation, it may be said that shoran consists of two radio beacons operating in the very high frequency band. The beacons are installed on the ground. A special transmitter, receiver, distance indicator, and computer are installed in the bomber.

The airborne shoran transmitter sends out a pulse of energy. This is received by one of the two ground beacons, which transmits a pulse of energy in reply. The length of time required for the pulse to go from the aircraft to the beacon and the reply to return to the aircraft is a measure of the distance between the aircraft and the beacon. This distance places the aircraft on a line of position on an arc that has its center at the beacon. The radius of the arc is equal to the distance between the aircraft and the beacon. A fraction of a second after it sends out the first pulse, the airborne transmitter sends out a second pulse of energy on a slightly different frequency to the second ground beacon. The distance between the aircraft and this second ground beacon is determined. This, in turn, places the aircraft on an arc with a radius equal to the distance between the aircraft and the second ground beacon. The point where the two arcs intersect marks the position of the aircraft. The airborne transmitter sends pulses alternately to each of the two ground beacons several times each second.

Loran (or long-range navigation device) cannot be used with any bombing system since it lacks the necessary pinpoint accuracy. It is, however, a useful tool of aircraft navigation, even though no longer a primary means of navigation. It consists of three or more ground transmitters and a receiver-indicator in the aircraft. One ground transmitter, called the master station, sends out a pulse of energy. When this pulse is received at another ground transmitting station, the "slave" station, it causes the transmitter there to send out a second pulse of energy. The pulses from the master and slave stations are both received at the aircraft. The time between the arrival of the first and second pulse is measured. If the aircraft is near the slave station and on the side farthest away from the master station, the difference will be relatively small. If the aircraft is near the master station and on the side farthest away from the slave station, the time difference will be relatively large. A line of position can be drawn on a map connecting points where there is exactly the same interval of time between the reception of the first and second signals. For example, if the navigator determines that 2,500 microseconds elapse between the arrival of the two pulses of energy at the aircraft, he can look at a special map, locate the 2,500-microsecond line of position on the map, and know that the aircraft is somewhere on this line.

To determine where the aircraft is located on the line of position, a second

slave station is required. The second slave station operates with the master station just as the first slave station does. The navigator measures the time that elapses between the reception of the signal from the master station and the second slave station. If he finds the delay to be 3,000 microseconds, the aircraft is on the 3,000-microsecond line shown on this map. The point where the two lines of position cross marks the location of the aircraft.

It takes a well-trained navigator about 2 minutes to measure the time that elapses between the reception of signals from the master and slave station, to locate the lines of position on the chart, and to determine the position of the aircraft (Fig. 30).

FIGURE 30. B–52 navigator plots a fix at his crew position during a routine mission.

Loran is most accurate in the area near a perpendicular drawn at the midpoint of the line connecting the ground stations. In this area, the lines of position cross at the most abrupt angles. When the lines of position cross so that they include angles of 90° to 30°, they provide acceptable fixes.

Since the aircraft merely receives information from the loran stations, there is no limit to the number of aircraft that can use one group of stations simultaneously. Since no information is transmitted from the aircraft, the system can be used without revealing the position of the aircraft.

Navigational fixes obtained from a worldwide network of space satellites will probably eventually modify the use of loran.

The Bombing Problem and Methods of Solution

Two classes of aircraft are concerned with the bombing problems—bombers and fighters. Both are concerned with the horizontal release of bombs, but

the fighter is also concerned with releases at angles and from positions other than the horizontal. Releases at angles varying from about 70° through about 20° from horizontal are normal for fighters when performing as bombers. Fighter bombing will be discussed later.

The bombing problem lies in the determination of a point in space where a bomb, or a number of bombs in a bomb load, when released, will strike a target.

For bombardment aircraft, this problem is solved by consideration of the factors of ground speed, air speed, altitude, degree of divergence from horizontal flight, and bomb ballistics. The methods of approach to this problem, when crew controlled, are by nonsynchronous or by synchronous bombing.

Nonsynchronous bombing, which is always conducted under visual conditions, employs a computer into which information about both altitude and bomb ballistics is fed, together with the approximate groundspeed and approximate rate of wind drift. The bomb run, or bombing approach to the target, is then begun. This approach, which is highly critical to the success of the mission, begins with the initial point (IP) and extends to the release point.

During a visual bomb run the bombardier makes adjustments to the approximate groundspeed and wind drift data which he has preset in the computer. He looks through the telescope of the bombsight and observes the relative motion between a set of cross hairs in the telescope and the target, or the predetermined aiming point. The cross hairs move within the telescope at a rate proportional to the groundspeed set on the computer. If the groundspeed has been set incorrectly, the cross hairs do not remain on the target or aiming point. By making adjustments, the approximately set groundspeed can be refined to match precisely the actual groundspeed.

If the rate of wind drift set on the computer is incorrect, the cross hairs will drift to one side of the target, since the aircraft will not be made to "crab" properly into the wind to make it pass over the target. By making adjustments, the rate of wind drift set on the computer can be precisely refined.

When the computer has accurate settings, the bombing problem is solved automatically. Bombs are released either automatically or manually.

Synchronous bombing may be conducted either visually or under conditions of nonvisibility. Under conditions permitting visual sighting of the target and aiming point, synchronous bombing is performed in a manner similar to the above. At the beginning of the bomb run from the initial point, control of the aircraft is taken over by the bombardier through an automatic arrangement in his bombsight. Synchronous sights permit an automatic and simultaneous computation of the wind drift and the dropping angle. When the aircraft reaches that point in space which will give the correct dropping angle, the bombs are automatically released.

When formations of bombers are utilized, it is normal for the lead aircraft in each formation to solve the bombing problem, while the others drop bombs simultaneously on signal. While all aircraft are capable of making independent bomb runs, this method concentrates the effort of the entire formation on the

ability of the most experienced bombing team (lead crew). During darkness or bad weather, a bombing formation executes individual runs over the target, and each crew performs individually.

The final category of crew-controlled synchronous bombing techniques involves the use of radar-bombing systems in the aircraft. During World War II, bombers flew at groundspeeds of 200 to 300 miles per hour. At such speeds the bombardier could use visual means and still bomb effectively when visibility was good. Since that war, the speed of bombers has increased. Bombs must now be released far from the target. For example, if a bomber is traveling at 600 miles per hour, the bomb run must be started at least 15 or 20 miles from the target, and bombs must be released about 10 miles from the target. Since the Air Force must be able to bomb all potential targets by day or night, regardless of weather, the bombing team must have equipment to supplement human eyesight. Airborne radar, along with ground radar and shoran, are used for this purpose. The latter two methods are ground-controlled and ground-assisted methods, respectively. Neither is usable at considerable distances from the ground stations.

In radar bombing, the bombardier looks at the scope of the radar-scanning device and follows the same procedures as in visual bombing. Cross hairs similar to those used in the visual bombsight are superimposed on the radarscope. The bombardier manipulates controls of the computer so that these cross hairs remain on the blip which represents the target. This adjustment refines approximate wind and ground speed initially set on the computer into absolute values.

The airborne radar-bombing system makes possible the attack of targets regardless of weather and visibility. This is no small factor in making possible a successful air offensive. When one considers that in Europe, for example, large areas on the continent are cloud covered during the majority of the days in the year and that in winter only some 5 to 8 days were open for visual bombing in each month during World War II, then the opportunities for a properly trained radar-bombing force are apparent. Such a bombing system is as essential to a modern air force, and to the aircraft that compose such a force, as an accurate system of navigation.

The operating principles of shoran and their applications to the navigational problem were previously covered. Shoran may also be used in bombing. Shoran, in this case, represents an example of a ground-assisted bombing system. Here ground stations are used to emit signals which are received and used by the shoran operator in the bomber.

Bombing by fighters may take two forms: horizontal, or dive or glide bombing. Horizontal bombing techniques have not been well developed for fighters, since this function is usually taken care of by bombers, which can carry a much heavier weight of explosive and deliver the bombs more accurately. However, some experimentation along these lines was conducted in World War II by the use of P-38 aircraft carrying a bombardier and bombsight, with a formation dropping simultaneously on signal.

Dive and glide bombing are essentially alike. They differ in the angle of

approach to the target. It is in these techniques that fighters have reached a considerable degree of perfection.

In the case of bombs and rockets particularly, the problem is one of determining that point in space where the armament must be released to hit the target. Historically, the fighter gunsight was used in dive bombing and rocketry.

The latest improvements involve the use of a gun-bomb-rocket sight which may be used in all three types of attack by fighters. The sight is adjusted for the type of armament being utilized. This sight automatically solves the fire control problems for gunfire from fixed guns, for bombing, and for rocketfire. The automatic feature enables the pilot to direct his full attention to the selected target. He must, however, fly the airplane so that a circular pattern of light, appearing on the windshield, is continuously superimposed on the target under attack. When this "tracking" action is performed correctly and smoothly, the airplane approaches a position from which its projectiles (shells, bombs, or

FIGURE 31. An Air Force fighter fires its full load of 104 2.75-inch Mighty Mouse rockets.

rockets) will strike the target. In the case of gunfire or rocketfire (Fig. 31), tracking should continue for 4 or 5 seconds, after which the pilot may close the firing switch. Bombs, however, may be released automatically by the mechanical sight when the airplane reaches the correct point on its approach.

LABS—Low Altitude Bombing System

This is an ingenious, simple, and effective delivery system for nuclear weapons (Fig. 32). The advent of nuclear weapons, threatening almost unlimited firepower, left unaffected scarcely a single aspect of warfare. This included conventional bombing techniques. These, used for dropping nuclear weapons, had serious deficiencies.

While nuclear weapon development brought increased yield, this was achieved with decreased weight and size. Weapons could be made small and light enough for compatibility with fighter-bomber aircraft. Fighter-bomber pilots had always sought to drive home dive-bomb attacks close-in to the target. This meant they had to respect the lethal radii of their own or adjacent aircraft's weapons.

Now, this consideration made diving on target impossible. The LABS turned the dive-bombing technique upside down. The aircraft releases the bomb while

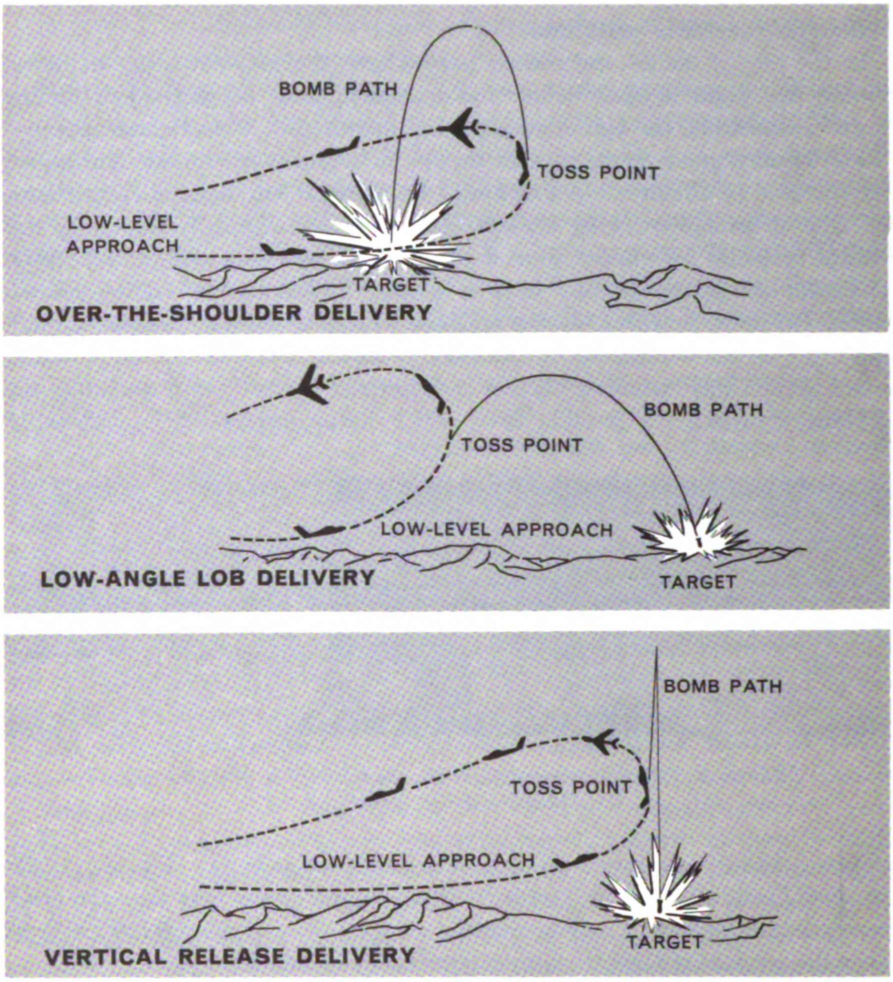


FIGURE 32. A diagram of the over-the-shoulder, low-angle lob, and the vertical release deliveries.

"diving" up from the target. The bomb thus has a "time of fall" or flight many times longer than in dive bombing. This, together with the much-increased release ranges possible, gives the delivery aircraft plenty of time for escape from even the largest yield weapons.

The pilot flies toward the target just high enough to clear the terrain and have good visibility. As it approaches the target the aircraft starts a smooth high-"g" pullup, and after bomb release completes an Immelmann or Half Cuban Eight. The pilot controls the maneuver. During the run-in to the target the optical gunsight is used for aiming the aircraft flight path toward the target. At the correct point, A, the LABS extinguishes the gunsight reticle. This is the signal for the pilot to pull up. Bomb release, which occurs automatically

during the pullup, is indicated to the pilot by the return of the gunsight reticle. In later-model LABS, the maneuver is flown automatically by an autopilot tied into the LABS, and the pilot just holds on for the ride.

At any time prior to pullup the pilot may select an alternate type of LABS release nicknamed "over-the-shoulder." In this mode of operation, the pullup may start just as the aircraft passes over the target or even past the target, and the resulting trajectory carries the bomb back to the target. This type of LABS would possibly be used under conditions of limited visibility where it may be desirable to fly closer to the target for positive identification. Two features of the "over-the-shoulder" are disadvantages compared to the "conventional" LABS release. The aircraft is exposed to much more of the target defenses, and its escape distance from the nuclear weapons effects is not as large.

The LABS went further than satisfying the requirement to bomb just below an overcast. It gave the fighter the capability of coming in at treetop level. Since radar is essentially limited to line of sight because of the wavelength it uses, its effectiveness for warning and for control of defense weapons against a treetop-level LABS attack is severely restricted.

Although the LABS was developed specifically for the fighter-bomber, two aspects of its operation were recognized as being equally applicable to bombers. The highly maneuverable B–47 was able to adopt the bomb-release technique in much the same manner as the fighter-bomber, and with practically the same degree of accuracy and safety.

The heavyweight B–52, while unable to imitate the bomb-release aerobatics of the fighters and the B–47, was able to adopt another principle of LABS which had not normally been considered in the repertoire of the heavy bomber. The idea of a heavy bomber flying at extremely low altitude had not been seriously considered, for its great size and comparatively slow rate of speed made it an easy target of defensive forces. The LABS technique, however, emphasized that low-flying aircraft could fly under the protective radar screens of an enemy. Beginning in November 1959, crews of the giant B–52's made it a regular part of their training to fly practice missions at an altitude of only 1,000 feet above ground obstructions, climbing suddenly to a bomb release altitude of 20,000 feet over the target. This ability to penetrate a potential enemy's defenses at low as well as high altitude greatly compounds his defense problems.

The Gunnery Problem and Methods of Solution

The gunnery problem is twofold: first, the application of gunnery in an air-to-air situation, where one aircraft is firing machine guns, cannon, rockets, or missiles at another; second, air-to-ground, where an aircraft is firing at a target on the ground.

Air-to-air gunnery is accomplished by fighters and by bombers. Fighters are generally on the offensive in such instance. Even fighters in air defense attack their targets offensively. Bombers, in this situation, nearly always fire defensively. Their offensive capacity is summed up in their ability to drop or launch bombs

on selected targets. Their gunnery systems are consequently designed to enable them to fight their way into, over, and out of a target area, by repelling attacks by enemy fighters. Light bombers, often used against ground targets, may employ their guns against these same ground targets, however, as well as drop bombs or fire rockets.

With this understanding of the situations involved, it will be noted that many variables are involved, but that in every case, once a target has been detected and located, there must be an accurate means of bringing the aircraft armament to bear accurately on the enemy to accomplish his destruction. This is a function of the aircraft sight and of the armament itself.

The latest gun-bomb-rocket sight automatically solves the fighter gunnery problem. This solution involves the accurate determination of the correct range, deflection (or lead), target speed, and fighter speed as well as the correct place and instant to fire the type of projectiles intended. For gunfire, the sight computes the angle between the line of sight of the pilot to the target and the boresight line of the fixed guns. It is a predicted angle. A radar component in the sight determines the range.

The sight operates similarly for both fighter bombing and rocketry. Whichever type of armament is to be employed is set into the sight by selection of the

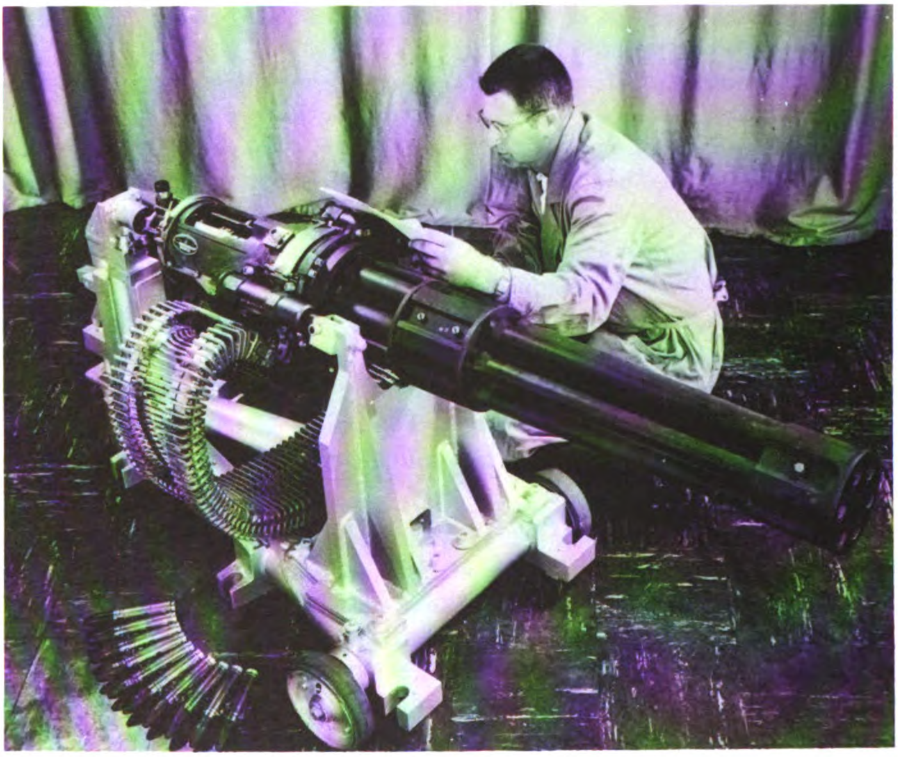


FIGURE 33. A new 20mm Vulcan gun has three times the striking power of the earlier 20mm model which is used on the F–104 "Starfighter."

correct switch. It may also be operated manually as a fixed sight with no prediction function being performed.

Harmonization between the sight and the boresight of the guns is accomplished on the ground. The aircraft is raised to flying position and the two elements are harmonized at a predetermined distance in front of the airplane. In World War II, for conventional fighters, harmonization was effected at 300 yards. At this point in front of the airplane, all guns directed their fire into an area 6 to 9 feet square. In modern jet fighters, with all guns mounted closely together in the nose of the aircraft, harmonization so exact is not so great a requirement. Most of these fighters are equipped with four to six 20-millimeter cannon to secure the greatest individual strike effect (Fig. 33). Rockets and guided missiles may be carried either under the wings of the airplane, beneath the fuselage, or concentrated in the nose, where the installation is retracted and covered to permit maximum aerodynamic efficiency.

In bombardment aircraft, the gunnery problem is simplified due to the fact that the aircraft itself generally maintains a straight flight path. Solution of the problem depends upon the deflection (or lead). Bomber guns are concentrated in power-driven electrical turrets to secure the best control and firepower.

These turrets were designed originally to protect the guns and gunners from windblasts and low temperatures at altitude, and to facilitate moving the guns against the slipstream at speeds necessary to track an attacking enemy.

All Air Force medium and heavy bombers are now designed to carry remote control mechanisms for these gun turrets. That is to say, the turrets themselves are no longer manned, but are controlled remotely from sighting stations. This fire control system is designed to deliver maximum defensive firepower of the bomber in any elevation of azimuth.

To detect approaching enemy aircraft, medium and heavy bombers may utilize an airborne search radar which operates to scan the sky around the airplane and warn the bomber of the location of the enemy, although he may not be seen visually. The importance of this device is highlighted by the great speed of jet interceptor fighters. It is quite possible for jet fighters to be in range and firing, or even to have completed their passes before the crew of the bomber is aware of their presence, if reliance is placed entirely on visual identification.

Eight of these H–1 rocket engines will be clustered to form 1,500,000 lbs. of thrust for the Saturn space vehicle.

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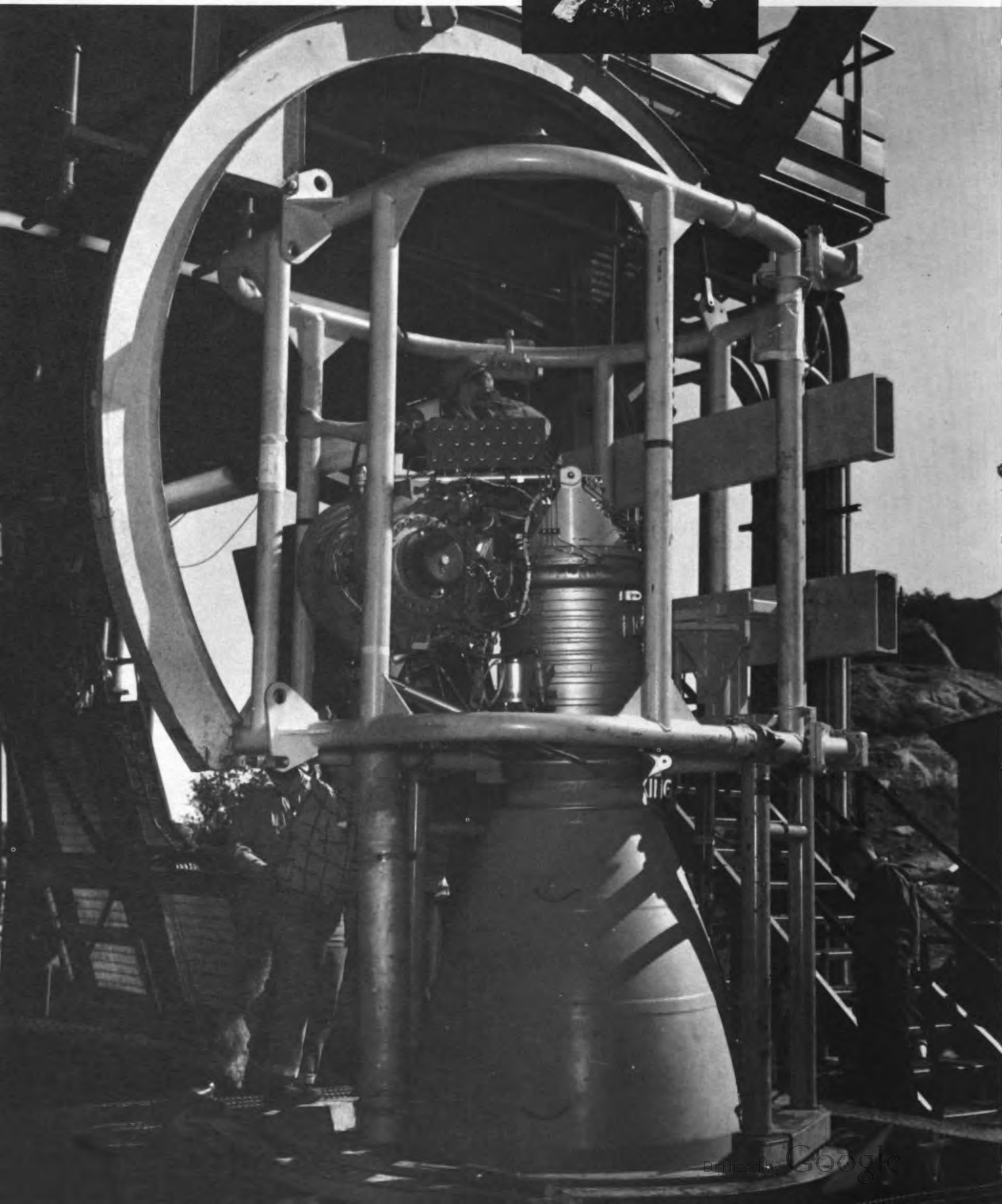


CHAPTER 5

PROPULSION

Systems

The term "propulsion system" refers to the equipment in an aircraft which produces the thrust force. In a jet or rocket, this is the engine alone. In a propeller-driven aircraft, it is the engine-and-propeller combination.

Rockets and jets are usually rated in terms of their thrust output in pounds of force. Reciprocating-piston engines, on the other hand, are customarily rated in horsepower.

Horsepower is a measure of ability to do a certain amount of work in a specified time. Thrust figures may be converted to equivalent horsepower figures (or vice versa) by a simple calculation. One horsepower is equivalent to 375

pounds of thrust moving at 1 mile per hour. Or, 5,000 horsepower is equivalent to 5,000 pounds of thrust moving at 375 mph. Or, to put it yet another way, at half that speed, or 187.5 mph, 5,000 pounds of thrust will do work equal to 2,500 horsepower.

The formula is given here only to provide a convenient way to compare the power output of jets and rockets with piston engines in terms familiar to the student. Crewmembers of jet aircraft seldom concern themselves with such conversions. They are trained to think in terms of thrust rather than horsepower, just as they are trained to think in nautical rather than statute miles, knots and mach numbers rather than miles per hour, and pounds rather than gallons of fuels.

In addition to providing sufficient thrust, a propulsion system must fulfill the requirements of dependability, reasonable weight, and economy.

To fulfill its requirements of dependability, it must operate under flight conditions, in the case of reciprocating and jet engines, for long periods of time without attention, while delivering an adequate amount of power.

In the design of a propulsion system, careful consideration must be given to the total weight—the engine, the propeller if there is one, the engine mountings, auxiliary systems, and the fuel that the engine must burn. With reciprocating engines and jet engines, a happy medium must be reached between the weight of the engine and the weight of the fuel. It would obviously be uneconomical to reduce the weight of the engine by 10 pounds if this required an extra hundred pounds of fuel for a flight.

To be economical, a reciprocating or jet engine powerplant must be able to burn a fuel that is as cheap and plentiful as possible, if it is otherwise satisfactory. Engines must be simple to maintain between overhauls, operate long enough between overhauls to be useful, and be reasonably inexpensive to manufacture. Naturally, the most economical engine for an aircraft or rocket is not simply the one that is cheapest to construct. To represent true economy, the initial and operating costs of the engine must be compromised with such factors as weight and performance.

In the early days of aviation the engines available did not fulfill the requirements we have outlined. They were erratic, undependable, heavy, and very expensive to build. After years of development the aircraft engine may now be said to accomplish what is required of it. With reasonable care and attention it will operate with unfailing regularity and deliver uninterrupted power. Rocket engines have not yet been developed to this degree.

Aerospace powerplants in present use have certain things in common. Although differing in appearance, they all derive their power to operate from principles governed by the same physical laws, and thus are fundamentally the same type of engine.

Some of the most important common denominators of present aerospace engines are:

1. They are all heat engines.
2. They are all internal combustion engines.

3. They all derive thrust through operation of the principle of reaction.

A heat engine operates from the liberation of heat; in present-day engines from the combustion of fuel. This heat is used to expand air or gases to produce work. It is a basic concept of physics that when heat is applied to a gas such as air, the gas will expand or its pressure will increase, or both. The increase in pressure can be used directly to produce work, as in a piston and cylinder. When the piston is forced to move by the pressure, it can be made to perform useful work, such as turning a propeller. In another type of heat engine, the expansion of heated gases is used to form jets of gas which produce thrust.

When we say that an aircraft powerplant is an "internal-combustion engine," we simply mean that the fuel is burned within the engine itself to produce the heat necessary for it to function. An example of a heat engine that is not an internal-combustion engine is the common steam engine, where the fuel is burned outside the pressure system to heat water and produce high-pressure steam.

The most common forms of reciprocating and jet engine fuels in use today are the hydrocarbons derived from petroleum. The best known are gasoline, kerosene, and diesel fuel. Some types of rockets also use hydrocarbon fuels. These fuels have certain desirable characteristics which make them practical energy sources in many engines.

1. They are volatile. That is, they evaporate quickly under suitable conditions and can be easily mixed with air to form a combustible mixture.

2. They ignite at relatively low temperatures. If the flashpoint (the lowest temperature at which a fuel will ignite readily in air) is too high, the engine will be difficult to start.

3. They have a very low freezing point, so there is no serious danger of their freezing in the tanks at high altitudes or during storage in arctic conditions.

4. They have a relatively high heat content. That is, they "burn hot," liberating a great amount of energy.

5. They are easily handled under fairly simple safety precautions. They do not require elaborate or complex safety procedures during storage or transportation.

6. They are relatively stable and do not deteriorate or become dangerous when stored for long periods of time at normal temperatures.

7. They are readily available at reasonable cost.

Within each type of hydrocarbon fuel, there are many grades. For proper engine operation, appropriate fuels must be used. When an engine is designed, the type and grade of fuel chosen has considerable bearing on details of construction and will be the most important factor determining the engine's ease of starting and restarting, operating temperature, and maximum power output.

Correctly speaking, a fuel exists only when one source of energy, such as gasoline, is mixed with another—oxygen. The oxygen is normally supplied from the atmosphere. Gasoline by itself, for example, will not burn in an engine, but must be mixed with oxygen to form a combustible mixture. By common usage, however, substances such as gasoline have come to be called fuels. Those engines which use the atmosphere as the source of oxygen are

called atmosphere-dependent engines. All the reciprocating engines and jets are included in this category.

At present, the only atmosphere-independent aerospace vehicle power plant is the rocket, which carries its own oxygen supply, either in pure form or readily utilizable from chemical compounds.

THE LAW OF ACTION AND REACTION

If we exploded a firecracker between two identical steel balls, we would expect the balls to roll away at the same speed (Fig. 34).

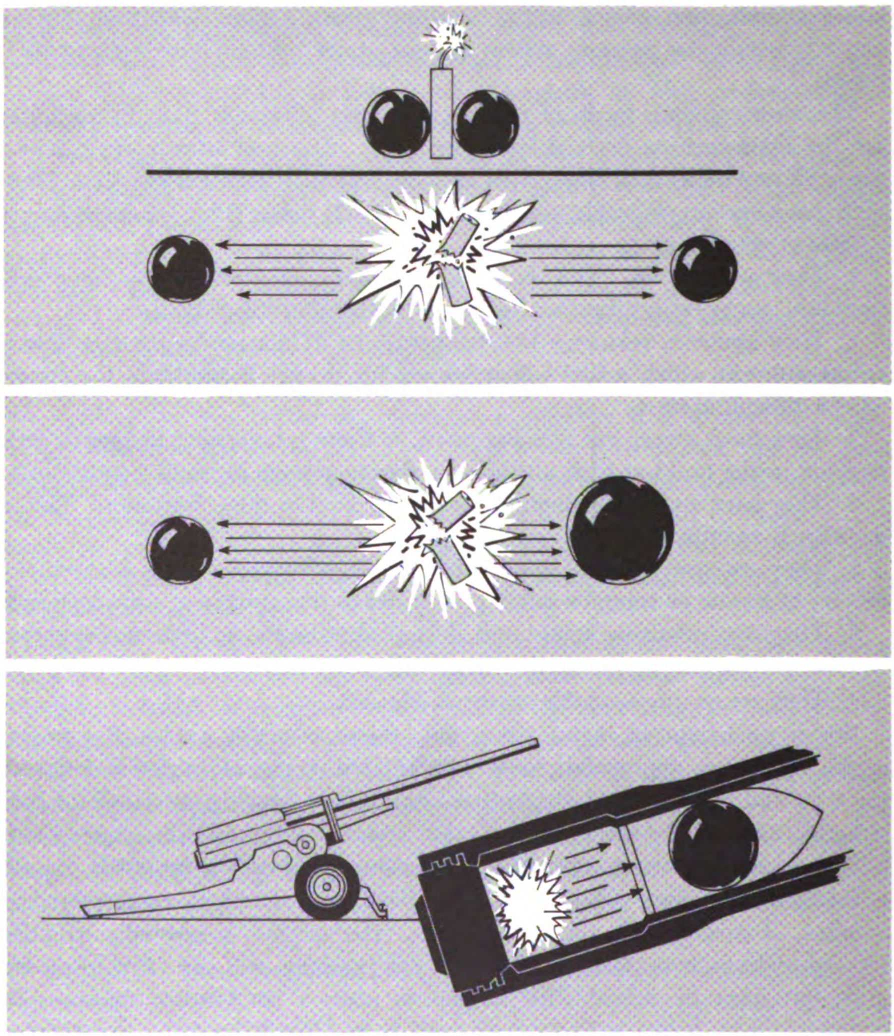


FIGURE 34. Action and reaction forces.

If one were heavier than the other, we would expect it to roll away more slowly than the light ball. We do not explain this to ourselves by claiming that less force was exerted on the heavy ball, but by pointing out that a certain amount of force can either move a large mass just a little, or a smaller mass quite a bit. We know, for example, that replacing the heavy ball with a cannon does not change the laws of physics. When the explosion occurs, the cannon will travel in one direction and the ball in the other. The cannon will travel only a few inches, while the ball may travel several thousand yards. But this is not because a greater force was applied to the ball than to the cannon; the two forces are equal. It is solely because the cannon is heavier.

The force applied to the ball is called the action force. The force applied to the cannon is called the reaction force. The applicable physical law states that "for every action there is a reaction, and that these two forces are equal and opposite."

There is no magic performed by choosing to call the force applied to the ball the action force. If we were interested in moving the cannon, and decided to do this by firing it, we might reverse our terms. This would leave the laws of physics quite unchanged.

If we now replace the cannon ball with a piston, and the cannon with a cylinder, and if the combustion is caused by igniting a mixture of gasoline and air instead of gunpowder, we can create an engine. Nor does this alter the law of action and reaction. The cylinder ("cannon") no longer moves from its position, but the force applied to it is no less. The cylinder is simply fastened down so tightly that the reactive force cannot move it. Leave the cylinder head loose and the reactive force will become immediately and violently apparent.

A common misconception holds that thrust is the result of rocket or jet exhausts "pushing" against the air, and so shoving the motor and vehicle forward. One observation will dispel this idea: rockets function in space, i.e., in vacuum, where atmosphere for practical purposes is absent. Indeed, they function more efficiently there, because atmosphere is a hindrance; for example, it presents resistance to motion of the vehicle.

ROCKET ENGINES

A rocket is, in a manner of speaking, an engine cylinder. In this case, the reaction mass is not a piston, but is the gas produced by the rapid burning of the propellant. Gas, a substance, has mass just as more solid substances; not essentially different, for example, from the kind of mass a piston has. The only difference is that, given a piston of gas and a piston of metal the same size, the gas has less mass.

Burning of fuel in either reciprocating engine or rocket will shove piston or gas in one direction (action) and cylinder or rocket housing in the other (reaction).

Fuel burning in a rocket is extended over a long period—a sort of continuous flame jet. This is accomplished by continually adding more liquid propellant.

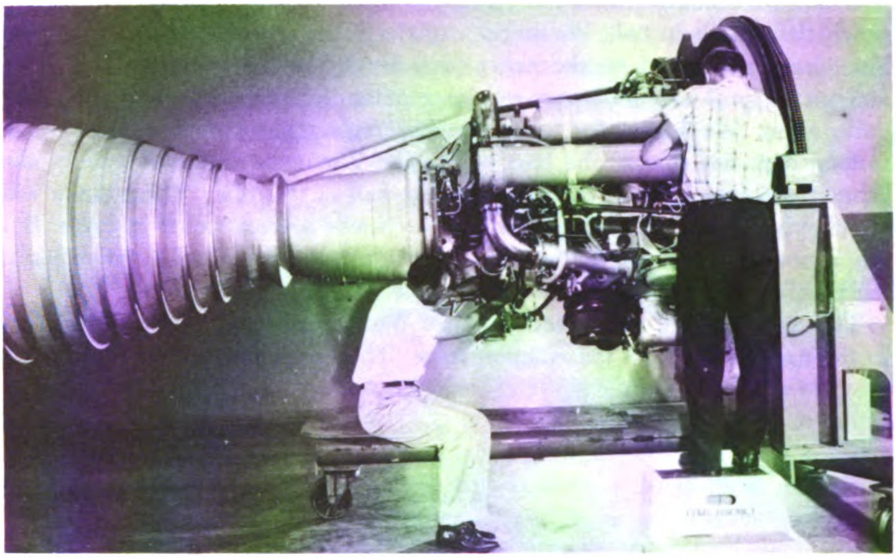


FIGURE 35. A "Thor" IRBM liquid propellant rocket engine.

If solid fuel is to be burned, more fuel is not added, but the original charge is burned at a controlled rate. This provides a continuous thrust force to drive the rocket forward.

One way of describing the efficiency of a rocket fuel system is to express it in terms of specific impulse. This is the constant thrust that can be produced by burning 1 pound of fuel per second. In more technical terms, specific impulse is pound-seconds of thrust obtainable by burning a pound of fuel.

Specific impulse is not the only criterion of the performance of a rocket. The ratio of the initial weight of the rocket engine to its final weight is also important. It is desirable to have this ratio large or, in other words, most of the weight should be devoted to fuel and not to the engine. A more important consideration is the achievement of the highest possible ratio of thrust to gross weight.

Thrust (the reactive force) can be increased only by increasing the active force. This can be done by either of two methods: (1) by increasing the mass of the gas shoved backward, or (2) by increasing the velocity at which the mass is shoved. Both methods may of course be used. In practice, for practical reasons, the gas is accelerated to the maximum possible velocity.

So far, the most practical method of obtaining the high ejection velocities required is by using a gas that expands very rapidly, and by requiring it to expand through a nozzle designed to accelerate the exhaust gases. When the gas expands, it has no space to expand into except out the back of the rocket. Consequently, it expands in that direction, at tremendous velocity.

The burning process in a rocket is like any other burning process in that the fuel must be mixed with oxygen before it will burn. In all other present-day

aircraft engines, this oxygen is obtained from the atmosphere. The rocket, however, carries its own supply of oxygen.

Solid Propellants

Solid fuel is stored in the combustion chamber, and the rate of burning is controlled by adjusting the burning surface area. Oxygen is supplied directly from the chemicals being burned. Burning pressure is usually 1,000 to 2,000 pounds per square inch, the exact amount being determined by the characteristics of the propellant.

Solid propellants can be divided into three groups according to their burning time. Fuel with a short burning time is used to give a relatively high thrust for a short period of time. When a high acceleration is required for a very short time, double-based powders of the nitroglycerine-gun cotton type are used. The specific impulse figure for such systems is around 250, corresponding to a jet velocity of about 8,000 feet per second. Rockets using solid propellants with a short burning time must be built strong enough to withstand the high acceleration forces.

The intermediate type of propellant, which has a burning time of 3 to 5 seconds, is used when the rocket is less rugged and less accuracy is required, or when guidance can be applied over a longer period. A typical use is for the barrage rocket. Double-based powders have been used for this purpose, but difficulties have been experienced in obtaining slow combustion rates. Therefore composite propellants, such as mixtures of sodium picrate and potassium or ammonium nitrate, are used instead. These composite propellants have a specific impulse of about 175.

Slow-burning propellants, which have a combustion time of 30 to 60 seconds, are used in the rocket-assisted takeoff of airplanes. A mixture of asphalt and potassium chlorate, called Galcit, is one kind. It gives a specific impulse of around 170. Since this mixture tends to be brittle when cool and soft when hot, it may both crack and flow. In either case, the burning surface area of the fuel increases, and failure results. It must therefore be stored and handled with care.

Solid propellants are almost always carried within the combustion chamber, and usually exist as single blocks. Thus, during combustion, the whole area where the propellant is stored is under pressure, and heavy construction is necessary. The weight is not particularly serious in small motors, but it becomes a major problem in the design of large rocket engines. The solid propellants also suffer from the disadvantage that the burning rate depends on the shape of the material, the initial temperature, and the pressure. Pressures of 1,000 to 2,000 pounds, which are usually necessary for obtaining satisfactory burning rates, require strong, heavy bases. The composite propellants and Galcit both produce large volumes of smoke.

The one real advantage of solid propellants is their simplicity. No pumps, valves, or regulators are required (Fig. 36). Most solid propellants can be stored easily over long periods of time and are thus ready for immediate use.

When a solid propellant is used, the storage chamber is a part of the combustion chamber, and no pumping or control system is needed, but the storage system must be heavy enough to withstand the high operating pressure of the rocket engine. It is for this reason that solid propellants have been largely limited to relatively short ranges.

Most of the modern solid propellant units employ a technique of manufacture in which the propellant is cast within the case, and through use of a bonding agent, is firmly cemented to the metal or plastic wall. The propellant grain, as the solid block is called, is sometimes cast with a hole down the center. This hole, called the perforation, may have a variety of shapes. Stars, gears, and other more unusual outlines are often employed. The choice of perforation shape and dimension is one way of fixing the burning rate, and time, and thrust, of the rocket motor. Other ways include composition and quantity of fuel used, and types of inhibitors used to slow the burning rate.

After being ignited by a pyrotechnic device, which is usually triggered by an electrical impulse, the propellant grain burns on the entire inside surface of the perforation. The hot combustion gases are ejected through the nozzle to obtain thrust.

The propellant grain usually consists of one of two types. One class of propellant resembles smokeless gunpowder in many ways. The second type, which is becoming ever more predominant, is the composite propellant. Here, an oxidizing agent is intimately mixed with an organic or metallic fuel. In choosing a propellant, not only is its behavior as a propellant important but it must exhibit satisfactory physical properties to withstand the handling and flight environment. For example, should the propellant grain develop a crack, upon ignition combustion would take place in the crack, rapidly increasing the area of burning surface with possibly disastrous results.

The chamber walls are protected from the hot gas by the propellant itself. Therefore, it is possible to use heat-treated alloys or plastics for chamber construction. The production of lightweight, high-strength cases is a major developmental problem for solid rocket motors.

The nozzles of solid rockets are exposed to the hot gas flowing through them. Therefore they must be of heavy construction to retain adequate strength at high temperature. Furthermore, various inserts must be used in the region of the nozzle throat to protect the metal from the erosive effects of the flowing gas.

Liquid Propellants

Liquid fuel systems offer better control. The combustion rate can be regulated by the rate at which the liquid is introduced into the combustion chamber. But some method must be provided for forcing the liquid into the chamber in proper amounts. In the small, short-range rockets, the liquids are usually introduced into the combustion chamber by tank pressure. In very large rockets it is more practical to pump them into the combustion chamber.

Liquid-fuel systems are either monofuel or bifuel. In monofuel systems a single liquid supplies both the fuel and oxidizing material. In the bifuel systems

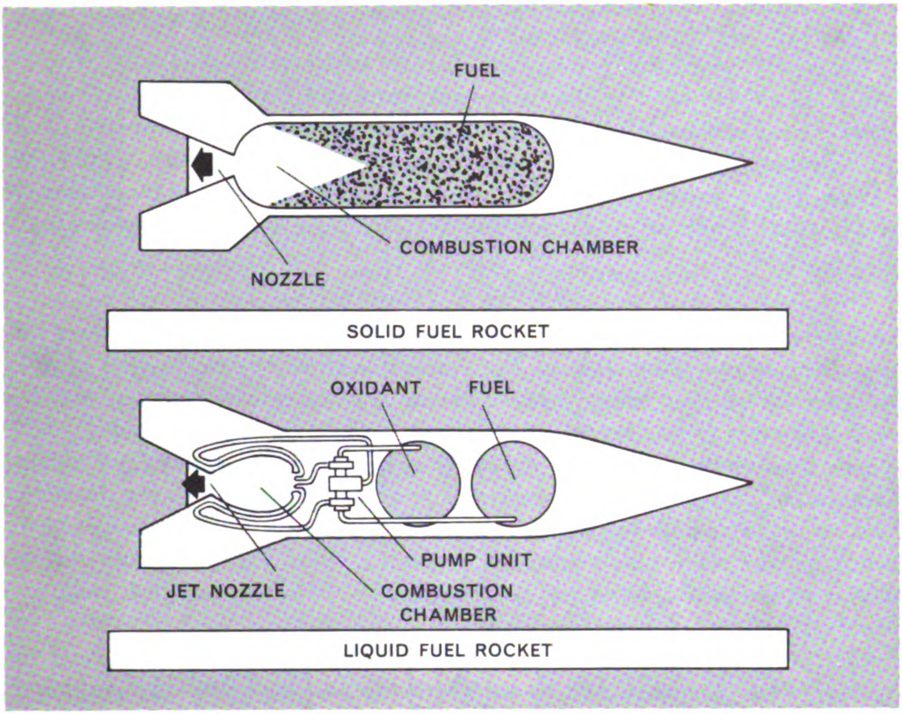


FIGURE 36. Solid versus liquid propulsion.

two liquids are used. One is the fuel, and the other is the oxidizer. Naturally, the bifuel systems are complicated, but generally they have the advantage that neither liquid by itself is explosive.

When liquid propellants are used, they are not ordinarily stored in the combustion chamber but are forced into it at a controlled rate. If the liquid is stored under pressure, the tanks must be of heavy construction, and the rocket has the same weight handicap as one burning a solid propellant. If the liquid is stored at low pressure, the storage tanks can be lightweight and the ratio of initial weight to final weight is more favorable, provided the rocket is large. In large rockets, ratios as high as 10 to 1 may be possible. Such a high ratio would make a tremendous difference in the range that could be obtained. However, the pumps and other equipment needed for low-pressure fuel storage systems weigh almost as much for a small rocket as for a large one. In small rockets, their weight nearly offsets the advantages gained by using the lightweight storage tanks. Low-pressure systems are most practical in large rockets.

Low pressure in fuel tanks means that much power must be developed to pump large quantities of fuel into the combustion chamber within a short time. High-thrust engines demand hundreds of gallons per second, and in order to achieve this, the pumping system must withstand pressures as high as 500 pounds per square inch. In many systems, the pumping power needed amounts to

several thousand horsepower. The system to generate this power is a hot-gas turbine, supplied from a gas generator.

The metals within the combustion chamber and nozzle would soon deteriorate if directly exposed to the great heat developed here. A common cooling method used in these places is to route the initially cold liquid propellant fuel through ducts or passages within the chamber walls. This, in turn, warms the fuel on its way to combustion. The whole system is beneficial to the efficiency of the entire combustion process, and the technique is called "regenerative" cooling.

Nuclear Propulsion

More serious consideration has been given to developing nuclear power for space vehicle propulsion than to the succeeding three "exotic" modes of propulsion. Nevertheless, many years of extensive technical development may be needed before a workable system can be produced. A nuclear powerplant would greatly increase both the speed and range of missiles and space vehicles, chiefly because nuclear power would provide a great power source of long duration. Also, in a nuclear-powered vehicle, the fuel supply, that is, the generator of heat, would remain practically constant throughout a flight. The propellant store in such a system would, of course, be dissipated in the rocket jet, and could not readily be replaced once the journey began.

The propellant in nuclear propulsion may be such material as water or hydrogen. Its function would be to absorb the heat generated in the nuclear reactor, thus vaporizing and pressurizing it, whereupon it would provide thrust when exhausted through a rocket nozzle. A light gas, such as hydrogen, is most efficient in terms of specific impulse.

Disadvantage in such a propulsion system would be the necessity for protecting all persons from radiation damage. Also, the problem of containing a fission reactor—producing perhaps enough heat to raise hydrogen gas to 5,200° F.—within relatively light metal walls is an easily apparent difficulty in the design of such a propulsion system.

Ion and Plasma Propulsion

Utilization of large quantities of electric power is a common feature of these proposed systems (Fig. 37). In the first, positively charged molecules, or ions, would be accelerated to exhaust velocity in an electrostatic field. These molecules have considerably more mass than their opposites, electrons, and are consequently more useful in providing thrust by reaction to acceleration of mass. The basic propellant material very likely would be a metal, such as cesium, which will ionize readily. To ionize it, the metal would be heated to vapor, and this plasma then brought into contact with an electrically charged surface.

Plasma propulsion theoretically could also result from accelerating electrically neutral plasma (consisting of both positively charged molecules and electrons) by magnetic means. Numerous variants of the above ideas for using electrical power and plasma may be lumped for convenience under the general term "electric propulsion."

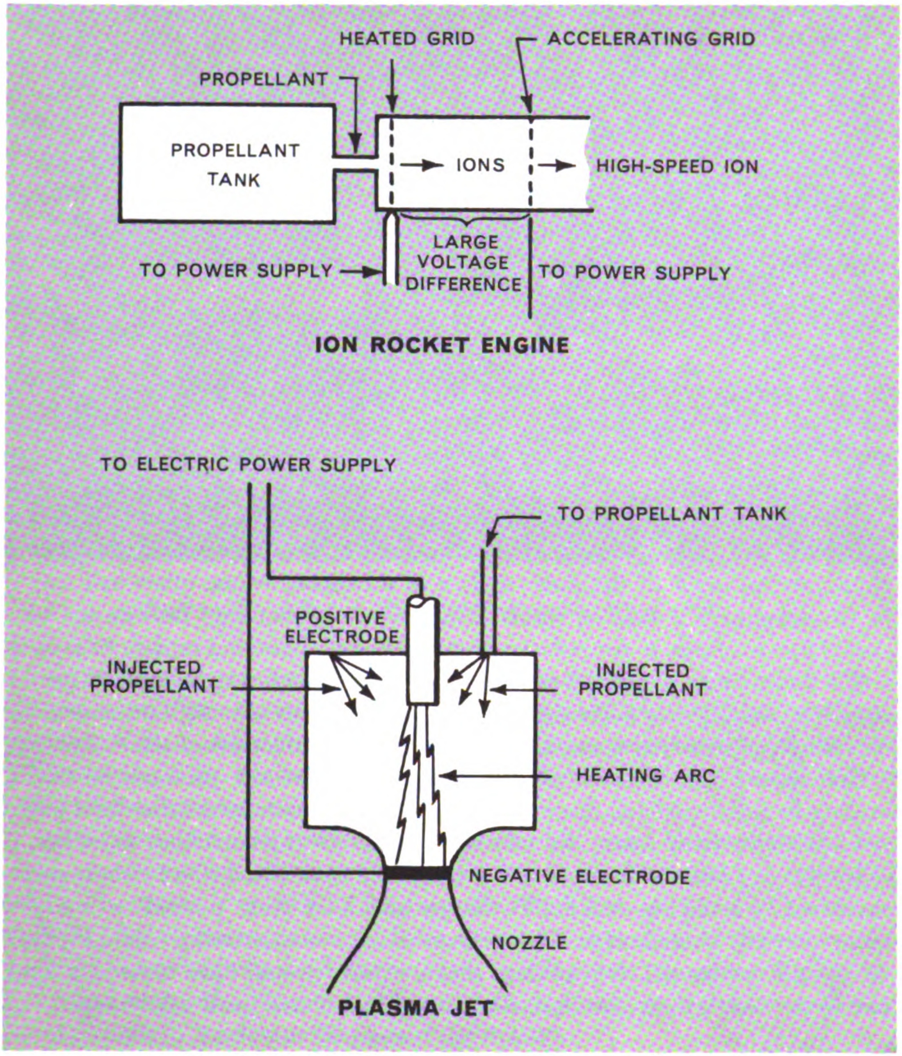


FIGURE 37. A comparison of the Ion rocket and Plasma jet engines.

Not the least of a legion of seemingly insurmountable problems to obtaining a working version of one of these ideas is the problem of producing the needed large amount of electricity. Pending evolution of radically new methods of generating electric power directly from atomic breakdown, rather than by producing heat as a first step in the energy cycle, a practical source of electricity might be a uranium reactor coupled with a turbogenerator. Another proposed primary source of heat is solar energy.

These types of propulsion would be of use only in low-gravity fields where low thrust would be useful and where rapid acceleration is not required.

Photon Propulsion

Since light is a form of energy, and may be regarded as separate particles (photons) having mass, in theory matter could be converted to light, and the energy thus released would be beam ejected to provide thrust. This scheme, if perfected, would constitute the ultimate in propulsion. One variation of such a system would convert matter carried as a reservoir in the spacecraft directly into energy. Another—the so-called photon ramjet—would collect interstellar matter for conversion into energy. Conversion of matter into energy has been accomplished in the laboratory in what is known as the electron-positron reaction. How to achieve this on a large scale is not known.

Solar Propulsion

Two types of spaceship propulsion derived from the sun's energy have been proposed. The first would collect radiant heat from the sun and concentrate it upon a propellant, such as hydrogen. The greatly heated gas would then acquire high velocity as it escaped pressure through a rocket nozzle. Solar energy would be collected by reflectors so arranged as to focus radiant heat upon a boiler containing the propellant. One idea for a reflector device would be to coat aluminum on one-half the inner surface of a balloon, whose other half would be transparent. The balloon would thus serve two functions: provide the concave shape necessary to the reflectors for focusing sunlight and radiant heat upon a boiler containing a propellant, and give relatively lightweight support for the structure. Fuel-saving advantages are apparent in this scheme, but countering disadvantages include the necessity for cumbersome collectors of solar radiation.

The second type of solar propulsion would utilize the pressure, or thrust, exerted by light particles. Since the theory of relativity assumes that light particles (photons) have mass, and because they travel at tremendous velocities, it is possible to postulate thrust. Indeed, photon pressure is an effect even now encountered by artificial satellites. The larger ones have been "pushed" by sunlight into materially altered orbits. Converting this idea to a spaceship would produce the so-called solar sail. It is evident that the "sail" would have to be very large to collect enough thrust. At best, the system would have small acceleration.

JET ENGINES

The initial development of turbojet engines in 1937 made higher aircraft speeds possible. Superior speed in military aircraft provides advantage in combat. The operational advent of turbojet-driven craft in the closing phase of World War II in Europe proved no exception to the above, and all air power nations began to further develop and use these power systems following the war.

Besides driving aircraft to supersonic speeds, the turbojet engine has permitted military operations at higher and higher altitudes. Not only more power but relief from inherent propeller deficiencies at high speed, and the more efficient streamlining possible without propellers and reciprocating engines, give jet-powered aircraft their superior performance characteristics.

FIGURE 38. A F–104 "Starfighter" jet engine is static tested.

The jet principle of thrust has been recognized for at least 2,000 years. Only in this century have technological and engineering arts permitted practical application of it in other than rocket engines. The greatest single deterrent to development of jet engines was the unavailability of the high-temperature-resistant metals needed in jet engines.

Jet engines, like reciprocating engines, depend upon the atmosphere for oxygen used in combustion. In jet engines, a portion of the energy developed within the engine is ejected in the form of a high-velocity jet of hot exhaust gases (Fig. 38). The reaction to the force ejecting the gases produces the thrust to move the aircraft forward. Similarly, in the rocket motor, thrust is obtained by expelling a high-velocity stream of gases through a nozzle. The reaction to the force required to accelerate the gases is the thrust.

Thrust is observed in the balloon that spurts forward when the air is released, the gun that recoils when the bullet is fired, and the simple gunpowder rocket that shoots out into the air when the powder is ignited. The thrust delivered by a jet or rocket engine is equal to the mass of the gas ejected from the engine times the rate at which the gas is accelerated as it is forced out of the open end of the tube. This is explained by Newton's second law of motion, which states that the resultant force acting on a body is equal to the product of the mass times the acceleration of the body.

If the flow of gas through jet or rocket engines is subsonic, a free-flowing fluid is accelerated when the cross-sectional area of the tube is made smaller. At the same time pressure and temperature are reduced. When the cross-sectional area of the tube is made larger, the velocity of the fluid is reduced and the

temperature and pressure are increased. In supersonic flow, the action is reversed.

Most of the engines described in this chapter have subsonic-flow velocities within the engine. The air entering a jet engine is slowed down from flight velocity to a relatively low subsonic velocity in the combustion chamber. The heated gases then speed up as they pass through the turbine and the tailpipe.

Five types of jet engines exist. They are the turbojet, ramjet, pulsejet, turbofan, and turboprop. The turbojet, turbofan, and turboprop are all versions of the gas-turbine engine. The ramjet and pulsejet have eliminated the turbine.

Turbojets

The turbojet engine is light in weight for thrust output. It is easy to replace or to service while in the airplane, and there is little vibration when it is in use. Engine instrumentation is simplified considerably. The engine has no reciprocating parts, no problems of cylinder cooling, and no ignition system, and the problems of lubrication and carburetion are only minor.

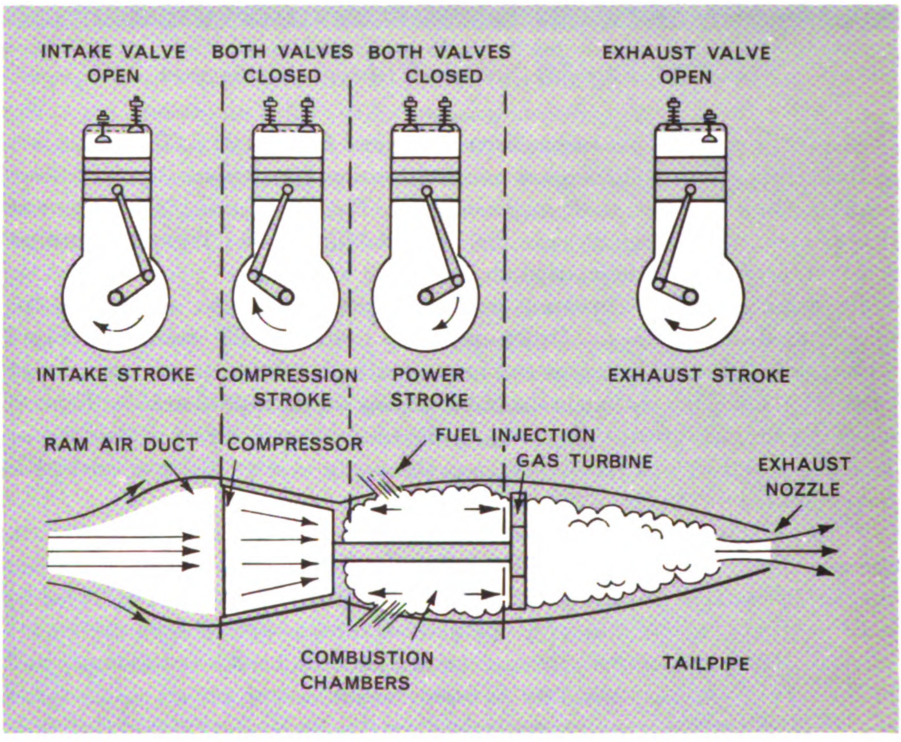


FIGURE 39. Reciprocating and turbojet engines compared. The four steps in the operation of a turbojet engine can be compared with the four strokes in the cylinder of a reciprocating engine. In the reciprocating engine, power is developed only once for each two revolutions of the crankshaft. In the turbojet engine, power is developed continuously as long as the engine operates.

The energy developed within the engine is used in the form of a high-velocity jet of hot exhaust gases. This produces the thrust necessary to move the aircraft, and the propeller problem is thus eliminated. The major problem in present jet engines is the high rate of fuel consumption. Improvements in this area are continuously being made.

The continuous operating cycle of a turbojet engine can best be described by comparing it with the four-stroke cycle of the reciprocating engine (Fig. 39).

In the reciprocating engine the four strokes take place in an orderly sequence in each cylinder. On the first stroke the piston moves down in the cylinder and a fresh charge of air-fuel mixture rushes in. This corresponds to the ram air entering the duct on the front of the turbojet. On the second stroke the piston rises in the cylinder and compresses the fuel-air mixture. This action is similar to the action of the air compressor in the turbojet engine. On the third (power) stroke of the reciprocating engine, the charge is ignited and burns. The heat energy released causes the gas to expand and forces the piston down. This action corresponds to the continuous burning and energy exchange that take place in the combustion chambers. On the fourth stroke the piston again rises in the cylinder and forces the burned gases through the open exhaust valve, an action similar to the one whereby the jet gases are exhausted.

In the reciprocating engine, the power stroke occurs once each two revolutions of the crankshaft. The pistons accelerate, stop, reverse direction, and accelerate again from 4,000 to 6,000 times per minute, depending on engine speed.

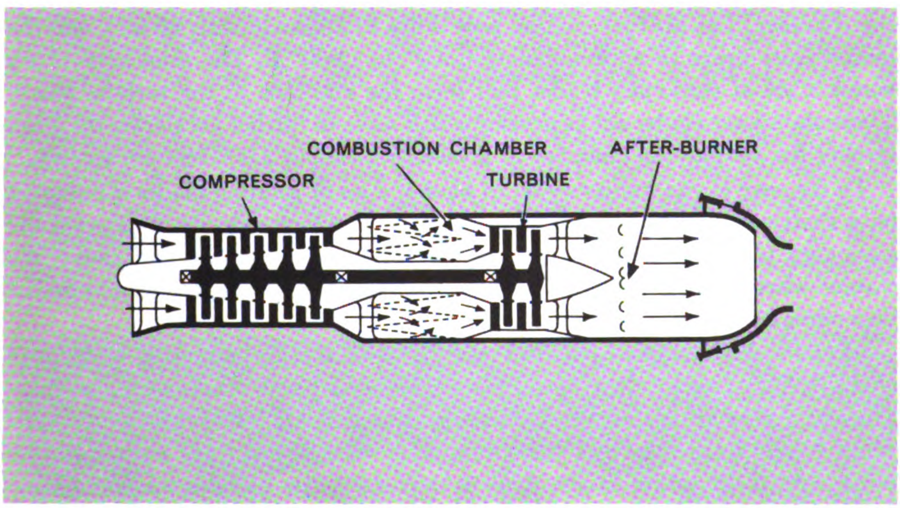


FIGURE 40. Turbojet engine with afterburner. The turbojet engine has three main parts: the compressor, the combustion chamber, and the turbine. The engine shown above also has an afterburner. Rammed air enters the compressor, where its velocity is decreased and its pressure increased. The compressed air is channeled to the combustion chamber, where fuel is injected and the mixture burns. The heated air expands, leaving the open chamber at a greatly increased velocity. The reaction to the force required to increase the velocity of the gases produces the thrust.

Each valve opens and closes approximately 1,500 times per minute, or 25 times per second.

The operating cycle of the turbojet is continuous. Power is developed uniformly. Since all large moving parts rotate rather than reciprocate, vibration is negligible.

The turbojet engine is composed of three major parts: the compressor, the combustion chamber, and the turbine (Fig. 40). The free air enters the forward air duct at a pressure and velocity depending upon the forward velocity of the aircraft and the temperature of the surrounding atmosphere. This rammed air enters the compressor, where its pressure is raised to many times that of the outside atmosphere. The mass of air leaving the compressor is divided at the combustion chambers. Approximately three-fourths of the air flows around the outside of the chambers to cool them. The other one-fourth of the air enters the combustion chambers, where fuel is injected at high pressure: about 700 pounds per square inch. The air-fuel ratio is approximately 14 to 1, and combustion is continuous. The energy released causes the temperature in the combustion chamber to rise to 3,250° F. The gases expand, but the pressure cannot increase because the combustion chamber is open at the rear. Therefore the expanded gases leave the combustion chamber at greatly increased velocity. Flow is not supersonic, however, because the speed of sound within the gases has increased with the higher temperatures.

After the gases leave the open end of the combustion chamber, they are again united with the mass of cooling air which has been flowing along the outside of the chamber. The air-fuel mixture now drops to approximately 60 to 1, and the temperature drops to approximately 1,500° to 1,600° F. The total mass of air enters a set of stationary blades that form the entrance to the turbine wheel. These stationary blades act as nozzles which serve to further accelerate the gases leaving the combustion chamber to a velocity of about 2,000 feet per second.

To the rear of the stationary set of blades, a set of rotating blades is mounted on a shaft connected to the compressor shaft. The high-velocity air leaving the stationary blades is directed onto the movable turbine blades and causes the turbine wheel to make 7,000 to 12,000 revolutions per minute, the exact number depending on the design details.

After the exhaust gases pass through the turbine, their temperature drops to about 1,200° F. and their velocity to 1,200 feet per second. Then, as these gases pass through the converging exhaust nozzle, or tailpipe, their velocity increases again until their exit velocity approaches 1,800 feet per second. At the same time the pressure of the gases is decreased, the gases expand and their temperature drops to 1,000° F.

Concerning performance of a turbojet engine, the thrust decreases with altitude, and since less power is being developed, less fuel is required. At high altitudes, where the density of the air is low, the drag of the aircraft is also low. The power required to propel the aircraft at any given velocity is proportionally reduced. Therefore, even though the thrust is less at higher altitudes, the aircraft can go almost as fast as it can at lower altitude where the thrust

and drag are both much greater. Since the aircraft goes almost as fast at altitude as it does at sea level, and since less fuel is required at altitude, the miles per gallon or pound of fuel are increased tremendously. In any mission where range or endurance is a factor, the turbojet engine must be operated at high altitudes—that is, at 35,000 feet and above.

The trend in the development of turbojet engines is toward more power, less weight, and lower specific (that is, more efficient) fuel consumption. Many methods of approach are being used to reach these goals.

While it is possible to increase the scale of all parts of a satisfactory turbojet engine so as to obtain a proportionally larger and more powerful unit, increased size in itself is undesirable. Whenever possible, it is preferable to increase the performance of all components. For example, the safe operating temperature for the inlet of the turbine may be raised above 1,620° F. either by developing materials that will maintain high strength at higher temperatures or by developing a system of air or liquid cooling for the turbine assembly. Extensive research is being conducted on both methods.

The efficiency of operation can also be improved by raising the compression ratio of the compressor. At present, the compression ratio may be as high as 14 to 1. Compression ratios of 40 to 1 are being considered. Raising this ratio causes other problems. The higher temperature of the more tightly compressed air will cause a higher temperature both at the turbine wheel and in the compressor itself. At present these temperatures are limited. The temperature of the air leaving the compressor may be reduced by some form of intercooler between the compressor exhaust and the entrance to the combustion chamber, but the installation of such a cooler would add weight and further complicate operation. The heat absorbed at the intercooler must be fed back into the engine, or a part of the energy will be dissipated as heat.

Increased thrust can be obtained from a turbojet engine by burning additional fuel in the tailpipe behind the turbine wheel where there are no moving parts. The excess air which is used for cooling the combustion chambers is sufficient to support combustion. The installation is referred to as an afterburner (Fig. 40). The additional thrust developed is large, but the operation

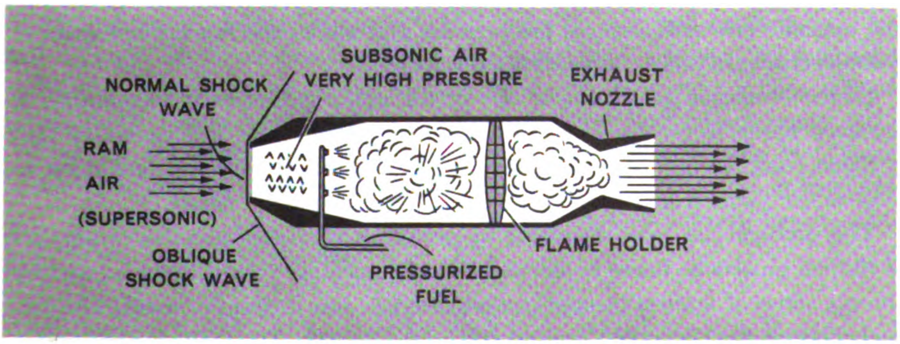


FIGURE 41. A typical supersonic ram-jet engine.

is very inefficient. Specific fuel consumption is increased two or three times when the afterburner is used to get the aircraft up to supersonic speeds. The afterburner appears to be practical only when a large burst of extra power is required for a short time.

Ramjets

In theory, the ramjet engine is one of the simplest engines that have yet been conceived for aircraft or missile propulsion. It is lightweight, and there are few parts. The subsonic ramjet engine resembles an open-end pipe. Both ends are necked down to a small degree, forming a divergent-convergent air duct. It has no moving parts with the exception of a fuel-pumping system.

The supersonic version differs mainly in the forward or diffuser section. In order to control supersonic airflow and the consequent shock waves affecting the pressure rise, a diffuser center body is added.

The basic operation of the ramjet engine consists of taking a mass of air, burning fuel with it, and ejecting the burned mixture rearward through a nozzle at a velocity greater than the entrance velocity. This net increase in velocity results in a forward thrust. The amount of thrust equals the mass of the gases admitted to the engine times the change in the velocity of the gases between the time they are admitted to the engine and the time they are ejected rearward.

In principle, the ramjet operates much as the reciprocating engine does, following the same four steps: intake, compression, power, and exhaust. Since the ramjet has no moving parts, such as the pistons of the reciprocating engine, it must be given some forward velocity before the cycle can begin. Thus, in the intake step the engine is moved forward so that air is rammed into the diffuser. The second step, compression, is performed partially by the diffuser, which is located in the forward portion of the engine (Fig. 41). The diffuser slows down the velocity of the air entering the engine and converts this velocity into pressure. In the third step, combustion, pressure is further increased by introducing fuel into the burning section and igniting it. This is the final part of the compression "stroke." The last step, exhaust, takes place in the nozzle of the engine. The expanding area within the diffuser serves to reduce the velocity of the air and increase its pressure; the decreasing area within the nozzle has the opposite effect. It reduces the pressure and allows the hot burned gases to exhaust rearward at a greatly increased velocity.

In the operation of a ramjet, one of the major problems is to maintain a constant flame front. Since the ramjet burns continuously, it is necessary that a flame front be maintained constant at one point. If nothing were done to control the flame front, it would be quickly blown out the nozzle.

The problem has been overcome by installing a series of annular or parallel **V**-shaped gutters or flame holders with the **V** opening toward the rear, and by using a series of igniters located in the gutters or just in front of them. The air-fuel mixture flow is stalled around the gutters, where it is ignited, and a constant flame front is maintained behind the flame holders (Fig. 41).

Another problem is the starting velocity required for the ramjet. The starting speed for the ramjet engine is something over 260 knots. Therefore some auxiliary means of power is needed to get the engine up to starting speed. The vehicle in which the engine is mounted may be attached to the wing of a fast aircraft, or be boosted to high speed by means of rockets.

In an overall evaluation of the ramjet, it must be borne in mind that, despite its ability to produce large amounts of thrust, it is still extremely uneconomical of fuel consumption. Only at supersonic speeds does the ramjet approach the reciprocating engine as a fuel economizer. As its speed increases, its thrust increases in proportion, and while the rate of the fuel flow does not decrease, the specific fuel consumption has decreased.

The ability of the ramjet engine to operate at supersonic speeds adapts it for use in guided missiles. To date, this has been its primary use. It is particularly well adapted to missiles designed to operate within the earth's atmosphere at high mach numbers and high altitudes. Ramjets may also be used as power augmentation to give short bursts of speed to more conventional aircraft.

Pulse Jets

Pulse-jet engines are so called because of their characteristic intermittent or pulsating combustion process. Like the ramjet, the pulse jet is simple in construction, consisting chiefly of a hollow tube with a constriction near the middle. A distinguishing feature of the pulse jet is the addition of automatic shutters at the intake end of the engine. These shutters open and close to permit intermittent entry of air to coincide with an intermittent injection of fuel. This fuel-air mixture, fired by a timed spark, burns and causes the air to heat and expand. The combustion chamber's raised pressure, behind the shutters, forces them to close. The heated gases are then forced out rearward at high velocity. As the gases leave the exhaust section there is a drop in pressure within the engine, whereupon air pressure in front of the shutters, caused by forward progression of the vehicle, forces open the shutters. This same cycle is repeated as often as 60 times per second.

Although simple in construction, the pulse jet is extremely noisy and is not efficient at high speeds. The pulsating explosions exhausting through the vent to the rear cause violent vibrations, which must be absorbed or dampened by careful mounting. Another limitation of the pulse-jet engine is its relatively short life. Because the air intake shutters must operate at a very high rate of speed, metal fatigue soon weakens the shutter springs and failure results.

The only noteworthy use of the pulse jet has been in the German V–1 "buzz bomb" used during World War II. These were launched to cruise at medium and low altitudes and were often overtaken by fighter aircraft powered by propeller-reciprocating engines.

Turbofans

A third variation of the gas-turbine engine is the turbofan engine, sometimes referred to as the ducted-fan or bypass engine. Actually this is a compromise

between the turbojet and the turboprop engine, which is described in the next subsection.

In the turbofan engine a portion of the air from the compressor bypasses the combustion chamber and the turbine, and is accelerated to the rear through an annular nozzle surrounding the tailpipe. The basic principle of the turbofan is that an additional mass of air is accelerated to the rear by an auxiliary fan placed in a duct around the main body of the engine. The auxiliary fan, or propeller, is driven by its own turbine operating in the exhaust gases of the engine, or it can be arranged to take its power from the regular turbine of the engine.

Because of its ability to augment the basic thrust developed by the turbojet, the turbofan engine gives more thrust at takeoff. This increase in thrust at the low speeds of takeoff can amount to as much as 150 percent of the basic thrust. The greater takeoff thrust and lower fuel consumption under cruise power make this engine superior in some applications to the normal turbojet for both military and commercial use. The reduced jet noise level makes this type of engine particularly attractive for commercial application.

Turboprops

Since much of the energy of the turbojet engine is lost in the wake of air behind the jet, engineers conceived the idea of using the same gas-turbine engine to drive a propeller rather than to produce a high-velocity exhaust jet. The result is the turboprop engine.

The turbine used to drive a propeller is essentially the same as that in the turbojet engine. In the turbojet engine, however, only enough power is absorbed by the turbine to enable it to drive the compressor. All the remaining energy is used to create the high-velocity jet. In the turboprop engine (Fig. 42) the turbine is designed to absorb all possible power from the hot gases, leaving

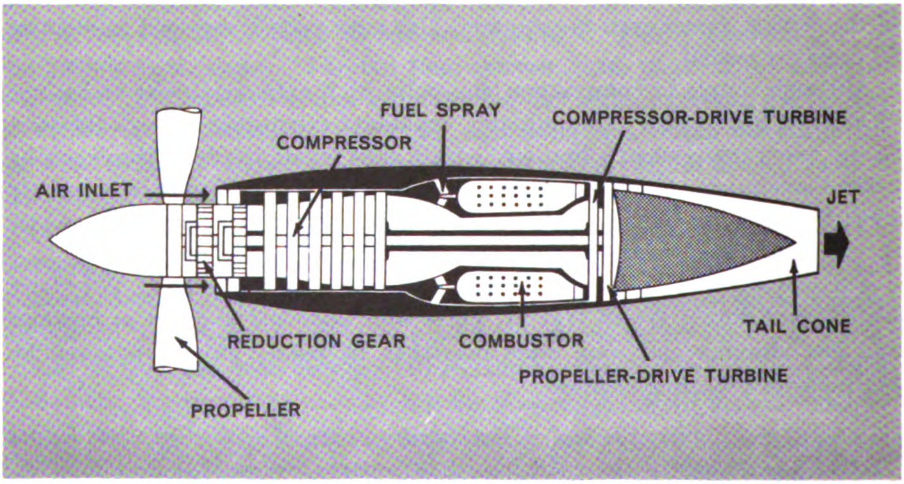


FIGURE 42. Turboprop engine.

only a very weak exhaust jet. The power produced by the turbine is far in excess of that required to drive the compressor, and this additional power is used to drive the propeller. The propeller, in turn, converts shaft horsepower into thrust.

Since most gas turbines have operating speeds of 7,000 to 12,000 rpm, it is necessary to have considerable reduction gearing in order to make the propeller shaft run at a satisfactory speed of 1,500 to 3,000 rpm. This gearing adds weight to the engine and further complicates the design.

Compared with the exhaust jet of the turbojet, the propeller of the turboprop engine moves a much larger mass of air at a considerably lower velocity.

The turboprop engine, while eliminating some difficulties, introduces new problems. The gas turbine is practically a constant-speed engine, and it operates near its maximum power at all times. In this respect, it is quite different from a reciprocating engine, and it creates a major problem in the design of a suitable pitch control and governing mechanism for the propeller.

Up to 8,000 horsepower can be supplied to the propeller by a large gas-turbine engine. This is more than twice the output of reciprocating engines in service today.

A turboprop powerplant could be developed that would be superior to the turbojet powerplant for low-speed operation. In some military operations, however, high speed cannot be sacrificed for superior low-altitude and low-speed performance. It may be necessary therefore to accept the inferior performance of the turbojet engine at low speed in order to attain high speeds.

PROPELLERS

The rocket and jet achieve their forward thrust as reaction to propelling a mass of gas backward. A propeller achieves its forward thrust from exactly the same process.

The propeller acts upon a standing mass of air in such a way as to give it a velocity in one direction. The result is that a velocity in the opposite direction is imparted to the propeller, and to anything (such as an aircraft) fastened to it.

Compared to the turbojet engine exhaust, a propeller with like power potential moves a much larger mass of air; however, it moves the air at a considerably lower velocity. This means higher propulsive efficiency for propeller-driven aircraft at low airborne speeds. Propeller-driven aircraft will give superior performance during takeoff, climb, and long-range, low-speed cruise.

The propeller can be likened to an ordinary electric fan, except that the angle of the fan blades is reversed so that a fan accelerates air ahead of it into a room instead of rearward past the motor. Both fan and propeller work on the same principle. If the fan blades were rotated backward so the air was pushed back instead of forward, we would have the semblance of a miniature airplane engine and propeller.

The air affected by a propeller is roughly equivalent to the area of the circle described by the turning propeller, so that the air moved rearward is in the form of a cylinder or tunnel of air.

We may regard a propeller as a small wing. The cross section of a propeller blade is very similar to that of a wing, for each is an airfoil.

Normally a propeller is designed to produce thrust in proportion to the maximum horsepower of the engine. If a more powerful engine is designed, then a corresponding change must be made in the design of the propeller. The size of a propeller is limited by such factors as ground clearance and the speed of the propeller tip. One way to increase the thrust potential of a propeller is to increase the number of blades. If carried to extremes, however, the addition of blades can reduce efficiency. When a larger propeller is required, a compromise is usually made between diameter and number of blades. Propellers have been designed with two, three, four, and sometimes five blades.

The modern aircraft propeller is an extremely complex machine. In addition to being strong enough to produce the thrust required of it, it is designed so that the angle of attack of the propeller blade may be changed in flight. There are two principal reasons for changing the blade angle of a propeller during flight. A propeller without this controllable feature would operate efficiently only at or near the rpm and forward speed for which it was designed. By controlling the blade angle it can be made to function efficiently over a wide range of speeds and rpm. The second reason for controlling the blade angle is to keep the engine running at a constant rpm. The engine can thus be made to run at its most efficient rpm, its rpm of maximum power, or any other that is desired. This constant engine rpm is obtained by controlling the angle of the propeller blades with a device known as a governor.

A propeller that incorporates a mechanism to control blade angle in flight is called a controllable-pitch propeller. If this mechanism is controlled by a governor to maintain a constant engine rpm, it is known as a constant speed propeller. Propellers incorporating these features are installed in aircraft only when the added weight and cost of the installation can be offset by higher or more economical performance.

RECIPROCATING ENGINES

Men failed in early attempts to fly for two chief reasons: insufficient knowledge of aerodynamics and lack of suitable lightweight power sources. A reasonably light power source was acquired last; indeed, some flying pioneers who preceded the Wright brothers might have succeeded first if their craft had been adequately powered. Their needs were obvious to the Wrights—an engine must be built that would be capable of producing relatively great power per unit of weight. The Wright engine of 1903 was barely adequate in these respects. Built by a Wright associate and excellent mechanic, Charles Taylor, the engine weighed approximately 180 pounds and had an output of about 30 horsepower; i.e., only one-sixth horsepower per pound.

Lighter and stronger materials, more powerful fuels, supercharging, better cooling, and more efficient arrangement of cylinders have all contributed since

that time to decrease the weight per horsepower in reciprocating engines to less than 1 pound per horsepower. The reliability of these engines is great.

Present models of aircraft reciprocating engines appear to represent almost the full potential of this engine type, and further improvement will be difficult to attain. One reason is that the speed of the propeller tip exceeds the speed of the airframe; the propeller tip enters the transonic zone while the aircraft speed is considerably below the speed of sound. In the transonic zone the thrust developed by the propeller drops off rapidly and a further increase in aircraft speed becomes impracticable. Jet and rocket engines alone can drive aerospace craft at sonic and supersonic speeds.

The reciprocating-engine-propeller arrangement differs chiefly from jet or rocket engines in that a propeller drives relatively larger masses of air rearward, with relatively lower velocity. However, engine-propeller arrangements have sharp limitations. As was noted above, when propeller tip speeds of revolution approach the speed of sound, propellers lose efficiency. On the other hand, the relatively small mass of gas that is accelerated rearward by jet and rocket engines can be increasingly accelerated beyond the capacity of engine-propeller limits by burning more and more fuel. Thus, the jet or rocket engine can deliver

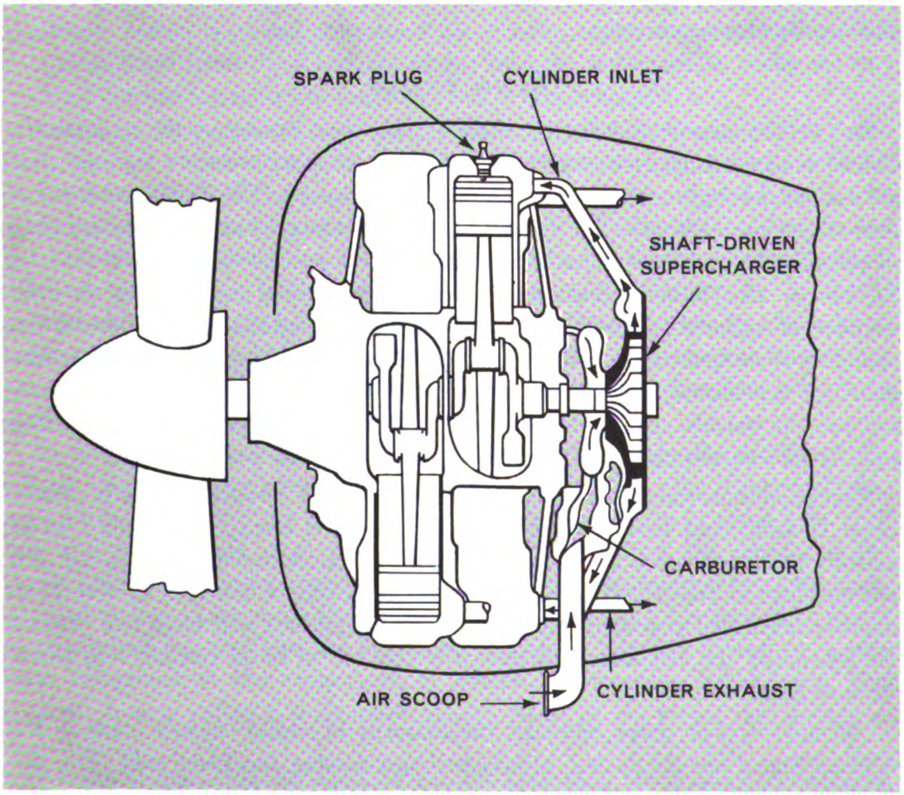


FIGURE 43. Cutaway drawing of a reciprocating engine.

more power per unit of time than the reciprocating-engine propeller. This means that they can be even lighter in weight in some cases than the piston-type engine.

The reciprocating engine, with its cylinders, pistons, valves, and other familiar features, still plays an important role in modern aerospace weapons systems. This engine is most efficient at speeds up to 400 miles per hour and at altitudes under 40,000 feet. It will carry more weight farther and use less fuel than any other type of propulsion system in its speed range. Coupled to a propeller, it forms a propulsion system still unequaled for over-all economy, flexibility, and reliability.

A reciprocating engine is one in which power is delivered in a back-and-forth movement of a piston or pistons. We see the law of action and reaction at work in two places in this propulsion system—in the action of the propeller shoving a mass of air backward so that the reaction force shoves the propeller in the opposite direction, and again in the cylinder where the piston is shoved downward by the explosion of the fuel-air mixture. The straight-line motion of the cylinder is turned into rotary motion by means of a crank arrangement, as illustrated (Fig. 43). The fundamental parts of the reciprocating engine are the carburetor, cylinders, pistons, valves, connecting rods, crankshaft, spark plugs, and air-ducting system.

Radial Engines

In the common radial engine there is only one throw on the crankshaft. Cylinders are arranged circularly around the crankshaft in such a manner that all the connecting rods operate from the single throw. The firing order for a four-stroke cycle requires an engine which will always have an odd number of cylinders in each row or bank of cylinders. It is possible to build a 3-, 5-, 7-, 9-, 11-, or 13-cylinder radial engine, but never a radial engine with an even number of cylinders in one row (unless it is the 2-stroke type). One of the cylinders is designated as a master cylinder. Its connecting rod fastens to the throw of the crankshaft with a normal bearing. All of the other conecting rods operate on swivels around the bearing at the end of the master connecting rod. These connecting rods are known as articulated connecting rods.

The maximum number of cylinders in each row in a radial engine is usually nine. If additional power is required, one radial is connected to the rear of another to make what is known as a twin-row radial. Although still a radial, this will produce an engine with an even number of cylinders; but it is, in effect, two engines connected together. In this case, the crankshaft will have two throws. By extending the crankshaft further it is possible to build radials with three, four, or more rows.

Because of their shape and size, the majority of radial engines made in the United States are air cooled, although liquid cooling has been used. The air-cooling system usually has the advantage of being comparatively simple, very sturdy and dependable, and much less vulnerable to enemy fire.

Functions of Other Engine Parts and Systems [1]

Although the reciprocating engine functions as a complete unit, its operation is more easily studied by a breakdown into smaller functions or systems. Such breakdown would include carburetion, ignition system, cooling systems, lubrication system, and various auxiliary systems or accessories.

THE CARBURETOR.—Internal combustion engines must be supplied with the correct mixture of fuel and air, which is taken into the cylinders, compressed, ignited, and burned to supply power. This process may be accomplished by use of a fuel injection system which includes an air-metering device, or a carburetor, in which air and fuel are properly mixed before entering the intake manifold and cylinders.

The carburetor must be able to provide the proper mixture (about 1 part of fuel to 15 parts of air, by weight) at all speeds. The correct mixture requires: (1) an idling system when the throttle is almost closed, (2) a main metering system for all other throttle positions, (3) an accelerating system to prevent temporary lean mixtures upon rapid acceleration, (4) an economizer system to supply extra fuel at higher engine speeds, and (5) a mixture control to allow for different air densities.

The throttle controls airflow through a restriction or venturi, in which a fuel discharge nozzle is placed. Increased air velocity causes a pressure drop, and fuel then flows from the discharge nozzle into the airstream. A wider throttle opening permits faster airflow and more fuel to be discharged.

Fuel must be vaporized and mixed with the oxygen in the air before it can burn. As fuel vaporization occurs, the mixture's temperature drops, sometimes as much as 60° F. Water vapor in the air may be condensed and frozen, even when outside air temperatures are as high as 80° F. Ice may collect on the butterfly valve (throttle) of the carburetor or in the intake manifold and, if allowed to build up, will cause engine stoppage. Carburetor ice is usually prevented by a carburetor air heater, which sends air, heated by the exhaust stacks, through the carburetor. Excessive use of the carburetor air heater may cause loss of power, or detonation; consequently carburetor heat should be used only when required.

At higher altitudes, the difference in pressure between the inside of the cylinder on the intake stroke and the outside atmosphere may be so small that air and fuel flow into the engine are greatly reduced without some help. Full fuel and air flow are restored by a supercharger; in fact, the density of the intake charge may be increased to more than twice that obtained by an unsupercharged engine at sea level. The supercharger is a centrifugal pump which forces more air-fuel mixture into the cylinders. It may be internal, driven by a gear train connected to the crankshaft, or external, driven by the exhaust. The external type is called a turbosupercharger. Most of the larger radial engines

[1] Portions of this section are reprinted, by permission, from "Fundamentals of Aviation and Space Technology," pp. 38–45, copyrighted 1959 by the Institute of Aviation of the University of Illinois.

have internal, integral superchargers, which have the additional responsibility of providing an even distribution of fuel to all cylinders.

Ignition System.—The compressed fuel-air mixture is ignited in the cylinder, at the correct time, by a spark from a spark plug. The spark is caused, in aircraft engines, by a high-voltage current developed by a magneto (Fig. 44). Here, as the permanent magnet rotates, a fluctuating magnetic field is developed in the

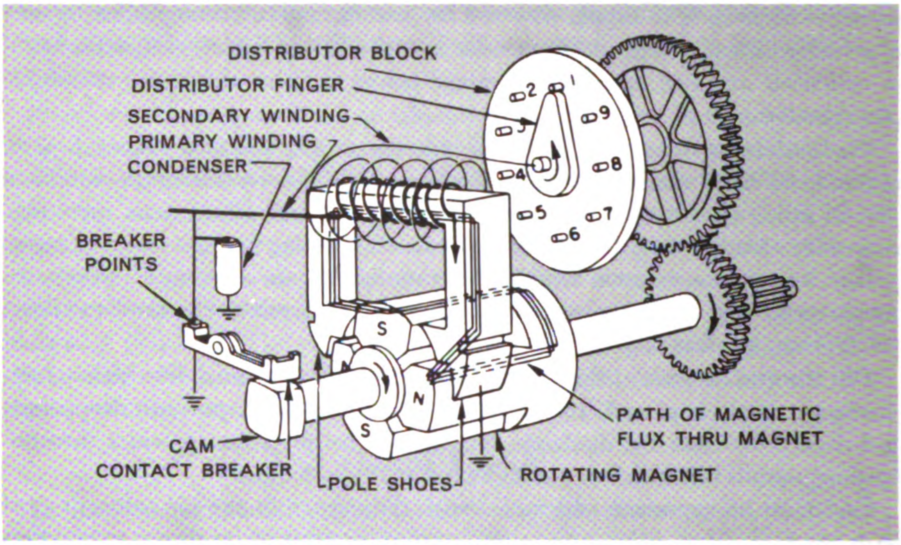


Figure 44. Schematic diagram of an aircraft engine magneto.

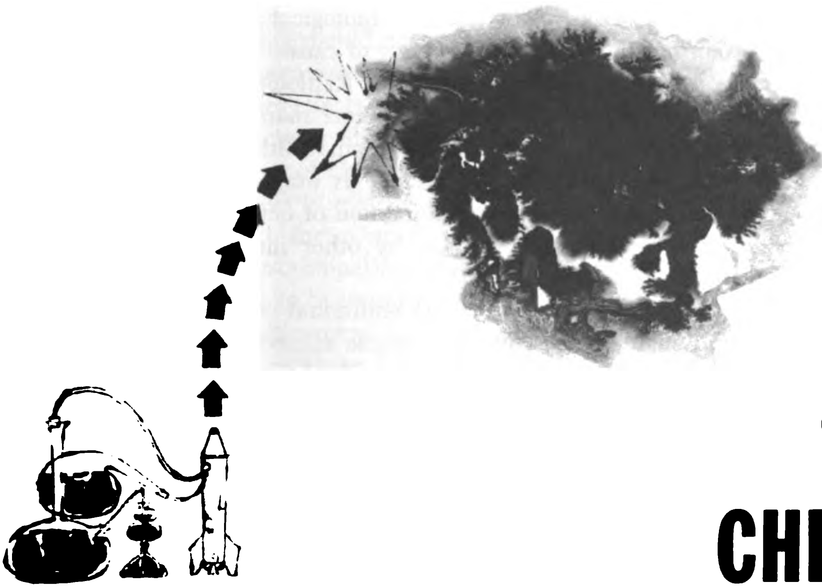
pole shoes, around which both the primary and secondary coils are wound. The change in magnetic field creates a low-voltage current in the primary circuit, which includes, besides a coil with a relatively few turns of fairly heavy wire, a condenser, a switch, and a set of breaker points. The primary circuit is interrupted by the breaker points, aided by the condenser, at the most opportune time; this causes a very rapid collapse in the magnetic field through the pole shoes. As a result, a high-voltage current is induced in the secondary circuit, which includes, besides a coil with many turns of fine wire, the distributor, ignition leads, and spark plugs. The distributor causes current to flow to the spark plugs in the correct sequence, or firing order. An aircraft engine usually has two complete ignition systems, with two magnetos and distributors and two complete sets of spark plugs, not only for better ignition but also as a safety factor.

Cooling Systems.—When the fuel-air mixture is burned in the cylinder, about a third of the heat produced is used to force the piston downward. About a third of the heat escapes through the exhaust valve and is lost to the atmosphere. But unfortunately the remaining heat is neither lost overboard nor used to perform work. It is trapped in the piston and in the walls of the cylinder. This

heat must be dissipated, and to do so requires cooling of the engine and oil. Radial engines are aircooled. This is accomplished by letting the air flow over thin flanges or vanes machined on the cylinder head and walls. This system alone is effective only at fairly low rpm, however, and several methods have been devised for assisting it. One of the most common is to construct a system of engine cowling, cowl flaps, and cylinder baffles which direct the air around the cylinder heads and aid in keeping the cylinders below dangerous temperatures.

LUBRICATION SYSTEM.—The lubrication system, besides performing the obvious and necessary function of lubricating the moving parts of the engine, has several other responsibilities; e.g., helps to cool the engine, provides for a better seal between piston rings and cylinder walls, prevents corrosion, and actuates hydraulic units such as valve lifters and propeller controls. Aircraft engines use a pressure-lubrication system in which oil is pumped through drilled passages to the many engine parts which require lubrication. Other parts, such as cylinder walls, and some roller or ball bearings, receive oil by splash and spray. The oil supply may be carried either in the engine's crankcase (wet sump) or in an external tank (dry sump). Radial engines are always dry sump. The dry-sump engine is so called because the oil which settles into the sump (collection place) is pumped back to the external tank as quickly as possible by a scavenging pump. If the external tank is very large, as in a large airliner, a small hopper tank within the main supply tank receives the oil pumped from the engine by the scavenger pump for recirculation within the engine. When the supply of oil in the hopper tank drops below the level of that in the main tank, additional oil is added from the main supply. Several benefits derive from the use of a hopper tank, the most important being a more rapid warmup of the engine.

AUXILIARY SYSTEMS (ACCESSORIES).—Auxiliary systems or accessories include those items which aid an engine's operation, but do not necessarily cause it to function. Most engines are equipped with electric starters which are usually powered by a storage battery. A second accessory, the generator, is required to recharge the battery that also provides power for lights, flap and landing gear actuating motors, radio equipment, etc. Other accessories found on many engines include vacuum pumps for operating certain instruments, and propeller governors which control propeller blade pitch to maintain a constant engine speed through wide variations in throttle setting.



CHAPTER 6

CHEMICAL *and* BIOLOGICAL WARFARE

Chemical and biological warfare are two types which have not previously been fully developed and exploited. Because of this fact they are relatively unknown and often misunderstood. They, together with radiological warfare, constitute an exotic trilogy of weapons to which the short term "CBR" has been applied.

CBR—the shorthand for chemical, biological, and radiological warfare—may be further defined as toxic warfare against man, his animals and crops, rather than explosive warfare which destroys both man and his material possessions such as buildings and machines. This definition excludes the "conventional"

◀ **Infantry troops in background watch a napalm explosion during weapons demonstration.**

destruction which can be caused by blast and heat from exploding nuclear weapons. Much emotion and controversy has been associated with contemplation of these forms of warfare.

CBR warfare suggests that there are developments which require consideration if the best possible military and defense posture is to be attained. Chemical warfare is the intentional employment of toxic gases, liquids, or solids to produce casualties, and the use of screening smoke of incendiaries. Biological warfare is the military use of living organisms or their toxic products to cause death, disability, or damage to man, his domestic animals, or crops. Radiological warfare employs the harmful ionizing effects of radiation against man, whether directly or indirectly, with nuclear weapon fallout the principal although not the only means for generation and distribution of agents. It may mean the effects which might be obtained by radiological contamination of enemy property or personnel by spreading radiological materials by other means than explosion of a nuclear device.

The CBR weapons, although requiring considerable additional research to realize their potentialities, are nonetheless relatively attainable at moderate cost by any nation on earth. The second characteristic which requires particular attention is that they can be used as weapons of stealth. A saboteur within the country, or a ship or submarine off the coast, under the right conditions could spread sizable amounts of some of these agents, covering thousands of square miles of territory. A third characteristic relates to the case of hiding the manufacture of very considerable amounts of such materials. The telltale signs, which might disclose nuclear experimentation, are lacking in chemical and biological weapons, and would be reduced even in some radiological experimentation. An old brewery or a drug house could be the cover for a considerable biological effort, carried on not only in the country planning their use but in a free enterprise country which was to be the intended victim.

The chemical and radiological aspects of CBR are the subjects of this chapter. The next chapter will again discuss CBR in terms of radiological warfare, but this will be combined with a general treatment of nuclear principles and their use in warfare.

CHEMICAL WARFARE

Chemical warfare is the military use of incendiaries, smoke, and toxic chemicals. Each of these categories consists of agent-munition combinations which may be designed for delivery from high-performance fighter or bomber aircraft. These agents may also be disseminated from cruise or ballistic missiles.

No combat restrictions limit the employment of incendiary, flame, or smoke weapons by local commanders in the accomplishment of their missions. The employment of toxic agents is a different matter, however. Whereas maiming and incineration are acceptable in war, the use of toxic chemicals is unacceptable because man fears most what he cannot see, feel, or hear. Although at the present time the United States has not signed any agreement which prohibits the use of toxic agents, this should not be interpreted to mean that it favors the

use of such agents. Also, consideration is given to the position of our allies who have signed such agreements. Both these reasons explain in part the historical reluctance of the United States to employ them.

While the use of toxic chemicals is closely controlled at a high level, chemical warfare is very much the business of the Air Force.

Air-bases are possible targets for chemical attack, and Air Force personnel may be called upon to assist in chemical warfare defense in nearby cities. Air Force commanders should know the agent-munition combinations available for conducting operations with incendiaries, flame, smoke, and toxic chemicals, as well as the target effects of such agents and munitions.

Two factors, either of which can be overriding, must be considered in the employment of chemicals: (1) meterology and terrain, and (2) logistics.

The effect of meteorological conditions on chemical weapons varies with the agent and the method of dissemination. The commander must therefore exercise discrimination in selecting the agent and the method of dissemination best suited to his requirements and the environmental conditions.

The employment of chemical agents is affected by meteorological factors—wind, temperature, humidity, cloud cover, precipitation, and air stability. The most important weather conditions are those existing in the zone of air from ground level to 30 feet above it. However, conditions at higher altitudes also influence the effectiveness of weapons delivered as an aerial spray. The effect of meteorological factors varies with the form in which the agent is employed. For example, chemical agents disseminated in vapor or aerosol form are affected principally by windspeed and air stability; liquid contaminants, by the surface temperature.

The terrain affects the employment of chemical and biological agents through its influence on the flow of air.

Incendiaries, flame, smoke, and toxic chemicals all require relatively large tonnages of ammunition to affect relatively small areas. For this reason such chemical weapons are practical only for coverage of small areas in tactical support of surface operations.

Incendiaries

Incendiaries can be used profitably under field conditions to set fire to buildings, industrial installations, ammunition, and fuel dumps. The mechanics of setting fires involve three essentials: a source of heat that acts as a match, a combustible material that serves as kindling, and the fuel. The incendiary supplies the match and the kindling, and the target supplies the fuel. Modern military incendiaries may be divided into three categories: oil, metal, and a combination of oil and metal; or they may be classified into two groups: those which owe their incendiary effect to a self-supporting exothermic, or heat producing, reaction and those which depend upon the presence of oxygen in the surrounding atmosphere for combustion (Fig. 45).

Planning for incendiary operations must take into account the preventive and defensive measures used by the enemy. Local firebreaks necessitate an

FIGURE 45. An incendiary bomb creates a fountain of fire as it burns.

increase in bomb tonnage on the target, and area firebreaks are important considerations in determining aiming points and force requirements.

Other factors that are vital in planning incendiary operations are the combustibility of the target and the ratio of the built-up area to the total ground area. Naturally, concentrations of wooden buildings will burn, and an empty reinforced-concrete structure will not. Since most incendiary targets are types of structures between these two extremes, a detailed analysis is necessary in order to determine the degree of combustibility. In making such analyses during World War II, professional fire-prevention engineers or persons of similar training and experience gave valuable service.

The type of product manufactured or stored would, of course, greatly influence the vulnerability of targets. A heavy fall of snow or rain would probably decrease the destruction caused by incendiary attack; a light fall of either would have little effect. Snow and rain decreased the effectiveness of attacks on Japanese cities by about 20 percent. Wind velocity is also of major importance, as brisk air movements cause local fires to spread into a general conflagration.

With the advent of nuclear weapons and their accompanying thermal effects, it is highly unlikely that incendiaries will be employed in any but limited war situations. Such use would probably limit targets to small towns or military installations, where attacks could not assume the same importance as World War II's incendiary strategic attacks against national morale. Nevertheless, the U.S. Strategic Bombing Survey (USSBS), an exhaustive study made immedi-

ately following World War II, concluded that attack with fire bombs was an effective psychological weapon against any target, and the effect was heightened by successive attacks. Other USSBS conclusions which would have application to future use of incendiary bombs follows.

Generally, the greatest World War II damage was inflicted when the total of incendiary bombs was released over a target in a short time; if the period of attack exceeded 2 hours, effectiveness fell off. Also, many bombs dropped close together were less effective than if properly spaced; that is, more effective if the dropping interval between bombs was lengthened properly. A small incendiary bomb was often just as effective as a large one in starting a fire; thus it was desirable to divide total weight that could be carried by an attacker into many small incendiary bombs, rather than fewer large ones. Interspersing high explosive bombs with incendiaries, up to 10 per cent by weight of the entire attack load, did not add to the total damage done to the target. Multiple aiming points within the target area produced more fire damage than if the attack had been aimed merely at the center of the target. The line of flight of an incendiary bomb-dropping aircraft was most efficient when at right angles to the wind.

Other USSBS conclusions in the same vein would have less application over the relatively small targets which might be the objective in a future war, but they cannot be ruled out entirely, even with the prospect of using modern equipment such as radar for sighting. These include the observation that daylight visual bombing was more effective than night bombing, as was low-altitude bombing. Also, target bombing with 200 tons per square mile apparently saturated the target; it was waste to concentrate bombs more than this. Finally, large targets (as an entire city) suffered more damage per ton of bombs than small targets, because fires had more opportunity to spread widely.

INCENDIARY AGENTS.—Incendiary agents ignite combustible material by flame or by generation of heat. They may also produce casualties in the event of direct bodily contact. Some agents are used as a primary incendiary for igniting secondary incendiary material; for example, in the casings of some incendiary bombs the magnesium alloy is ignited by the thermate filling of the bomb. The standard incendiary agents, with the symbol, common name, description, and type of weapon using them, are shown in Table I.

INCENDIARY MUNITIONS.—The three standard incendiary munitions used by high-performance airplanes are the M126, a 4-pound thermate-filled bomb; the M74A1, a 10-pound PT–1-filled bomb; and the M116A1, a 750-pound fire bomb filled with gelled gasoline, or napalm, so called because of its similarity to a thickener used in World War II. These three bombs are primarily antimateriel weapons to be employed in limited wars.

M126 (4-Pound Bomb).—This bomb uses a thermate filling and magnesium case. The flipout tail fins and the hollow sheet-iron tail stabilize its flight after it leaves the cluster.

M74 (10-Pound Bomb).—During World War II the M50 bomb penetrated too deeply for effective use against the light structures in Japanese cities. Fre-

TABLE I.—*Symbol and Description of Standard Incendiary Agents and the Air Chemical Munitions Using Them as a Fill*

Symbol	*Name*	*Description*	*Air chemical munitions using agent as fill*
PT–1	Incendiary mixture PT–1.	Grayish-black solid consisting of isobutyl methacrylate polymer, magnesium powder, oxidizing agent, petroleum distillates, and gasoline; burns fiercely and fast; difficult to extinguish.	M74
NP and OT.	Incendiary oil NP and OT.	Incendiary gels composed of thickeners and gasoline.	Fire bomb M116A1
TH	Thermate	Basically a mixture of iron oxide, aluminum, and certain oxidizing agents; burns violently, producing a very high temperature; impossible to extinguish.	M126
Mg	Magnesium	A solid used as the body for 4-pound incendiaries; burns brilliantly and at a high temperature.	M126

quently the bombs fell through the buildings and buried themselves in the earth, where they burned out and caused little damage. The M74 bomb, which was developed for use against light buildings, could penetrate an average Japanese roof without going too deep.

The M74 consists of a hexagonal sheet-steel casing filled with PT–1. The bomb also contains a small amount of white phosphorus, which ignites upon impact and then ignites the incendiary fill.

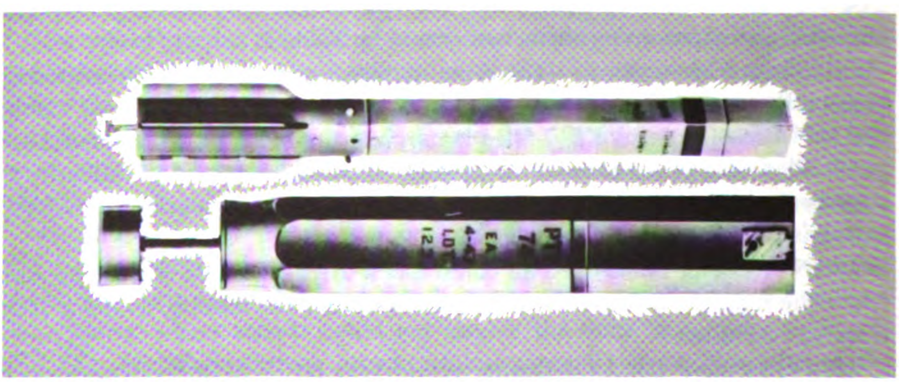


FIGURE 46. The M126 (top) and the M74 (bottom) incendiary bombs.

The bomb is stabilized by a metal tail fin, which is compressed into the body of the bomb to save space for packing in standard clusters. When the cluster opens and the bombs are released, the tail fins are forced out by a spring located in the tail well.

The two small bombs, the M74 and the M126, are effective in residential areas, storage and industrial plants, and firmly built structures protected by 3 to 4 inches of reinforced concrete or its equivalent (Fig. 46).

Incendiary Clusters.—The standard incendiary clusters, which are aimable from high altitudes, are made up of small component bombs, adapters (metal parts which hold the cluster together), semicylindrical or cylindrical sheet-steel sides, fin-type tail assembly, and fuzes. The Air Force inventory includes two side-opening clusters: the M35 cluster, which contains 57 M74 10-pound incendiary bombs and the M36, which contains 183 M126 4-pound bombs (Fig. 47).

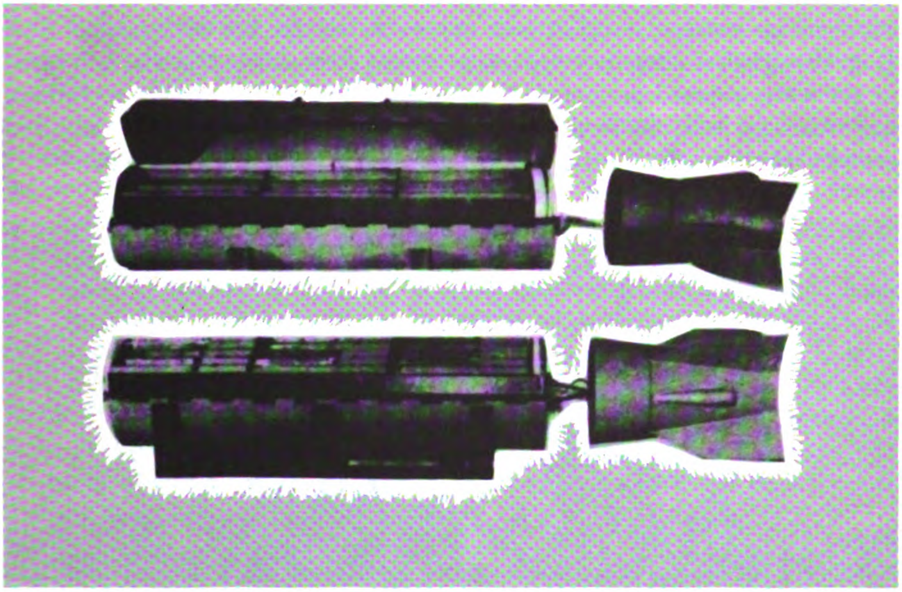


FIGURE 47. The M35 (top) and the M36 (bottom) incendiary clusters.

Fire Bombs.—Considerable use was made of fire bombs against tactical targets during the latter part of World War II and in the Korean war.

Originally the fire bomb was an aircraft fuel tank to which were added two igniters containing white phosphorus. The fuel tank was filled in the field with gelled gasoline which had been thickened with napalm, a mixture of metallic soaps. The present model of the fire bomb, the M116A1 (Fig. 48), was designed specifically for delivery by high-performance jet airplanes. When released at low altitudes, the tank and the igniters burst upon impact. The igniters are filled with white phosphorus, which immediately ignites upon contact with air.

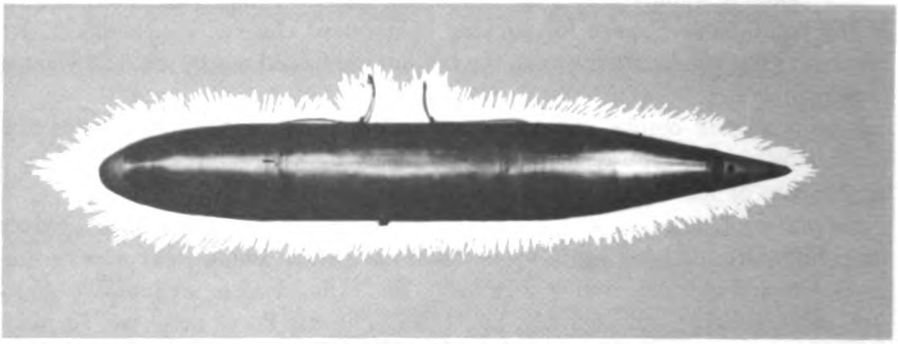


FIGURE 48. The M116A1 fire bomb.

The burning white phosphorous in turn ignites the gelled gasoline. The blazing contents are scattered over an area approximately the size of a football field (Fig. 49). The resulting flash fire ignites readily combustible material and burns or suffocates exposed personnel. It is particularly useful in jungle operations, against troops in lightly fortified positions, and against tanks or other armored vehicles. However, the fire bomb is primarily an antipersonnel weapon.

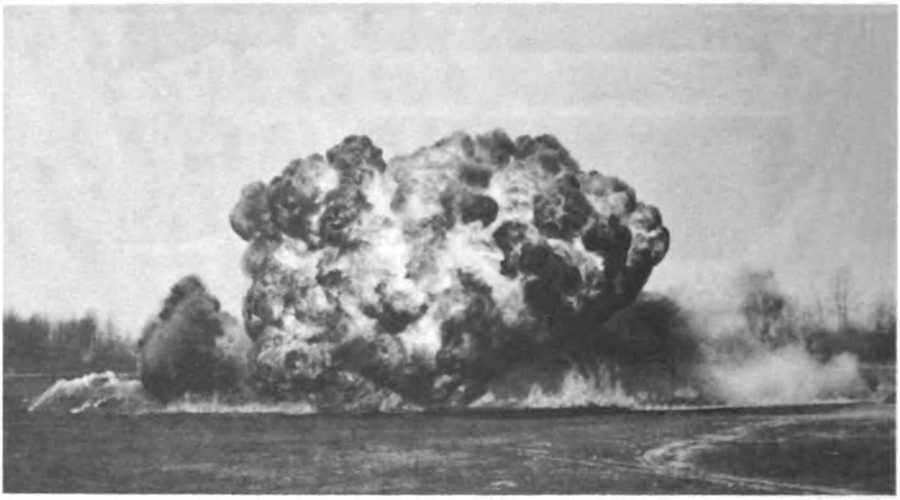


FIGURE 49. Explosion of a fire bomb.

Smoke

Smoke is used to conceal. Concealment can prevent observations by the enemy, reduce the effectiveness of his fire, or hamper his operations by deceiving or confusing him.

Smoke used to prevent observations and otherwise interfere with hostile

activity is called a "smokescreen." If smoke is placed directly upon a target to deny vision and hamper enemy activities in the immediate area, it is called a "blinding smoke." If a vertical smokescreen is laid to conceal friendly troops or installations from enemy ground observations, it is called a "smoke curtain." Smoke placed over, rather than upon, a target is a "smoke blanket." Sometimes it is desirable to cover a friendly area with a light concentration of smoke to prevent enemy observation from a distance yet permit local activity and observation. This is a "smoke haze."

Principles of Employment.—Each situation determines the type of smoke tactics to employ. Each situation must be studied on the basis of the following information: the objective of the operation, the terrain, relative positions of the two forces, and the weather. After these conditions are evaluated, it is necessary to determine the point of release and the munitions required.

Smoke is valuable for signaling or marking. The Air Force uses signal smoke bombs or colored streamers for target identification, and ground units designate targets for supporting aircraft by means of artillery or mortar smoke shells. Colored smoke grenades, used according to a prearranged code, can identify frontlines or friendly patrols.

Aerial smoke operations support ground forces in amphibious landings, river crossings, bridgehead assaults, airborne operations, protection of flanks, screening movement, withdrawals, armored operations, and target marking. Smoke can blanket antiaircraft or searchlight positions and provide cover for low-altitude attacks.

Each operation dictates the type of smoke tactics required. Amphibious landings, for example, are usually best supported by smoke curtains laid near the beach; cover for low-level airplane attacks might require a horizontal blanket laid at some predetermined altitude on the target approach line, or a small blanket concentrated over specific antiaircraft positions. In any case, the smoke must be sufficiently dense to provide concealment. In addition, a reserve of smoke munitions must be available to reinforce weak spots in the smoke and to renew it as necessary.

Reinforcing and renewing the smoke is the most difficult part of the operation. Because these missions are hazardous for airplanes to perform, ground weapons should be used instead, whenever practicable.

Smoke operations are primarily tactical, having only limited strategic value. High-altitude radar bombing may negate the future use of smoke to cover cities or airbases. However, if smoke is used to defend airbases, the Air Force can call upon smoke generator units of the Army.

Smoke Agents.—Several solid and liquid agents have been developed for chemical smoke munitions. The solids must burn to produce a smoke cloud, and the heat thus released results in a major disadvantage—the pillaring of smoke.

Liquid smoke agents are designed for spreading from airplane spray tanks. Of the several liquid agents that have been developed, only one is standardized: a solution of sulfur trioxide in chlorosulfonic acid (FS), a heavy, oily, and corrosive liquid which reacts with the moisture in the air to produce an opaque

white smoke. The smoke actually consists of extremely small droplets of dilute sulfuric and hydrochloric acids that eventually settle to the earth. If sufficiently concentrated, this smoke is irritating to breathe, although harmless. Because the droplets are corrosive to both metal and cloth, the use of this smoke is carefully controlled near friendly units.

SMOKE TANKS.—The advent of high-performance aircraft required the development of a new smoke tank, the E33. Designed for laying smoke curtains from high-performance aircraft, this tank contains small perforated spheres suspended in, and filled with, liquid FS. The entire contents of the tank are ejected, and the spheres lose drops of FS as they fall. Thus each tank can provide a curtain of smoke extending from aircraft to ground level and several hundred feet in width.

Toxic Chemical Agents

Toxic chemical agents were not used during World War II or the Korean war; the Allied forces agreed to use them only in retaliation. It is possible that in World War II, Germany was deterred from using toxic gas weapons only because it lacked the necessary air superiority when their use would have been to its advantage.

Since our experience with gas during World War I, warfare has changed radically. The development of techniques for the aerial delivery of weapons has thoroughly altered ground deployment and tactics.

Because of their nature, toxic chemical agents are of primary value for use against personnel. Other weapons of more conventional nature and of war-proved value, such as fragmentation bombs, are designed specifically to be used against personnel. The toxic chemical weapon must be considered as a possibility, however, because of two characteristics not possessed by other antipersonnel weapons.

From the standpoints of effectiveness and economy, the airplane is the best vehicle for use in delivering and employing toxic chemical weapons. If the decision should be made to employ toxic chemicals, about 80 percent of the tonnage would be used in Air Force munitions and about 20 percent in ground force weapons.

The terms "war gas" and "poison gas" came into use during World War I when chlorine and other true gases were employed. Since then a great many chemical compounds, not necessarily gases, have been experimented with to determine their suitability as agents for toxic munitions.

SUITABILITY CRITERIA.—To be suitable, the compounds must be (1) highly lethal or incapacitating to man, (2) difficult to detect, (3) available in large quantities at a reasonable cost, (4) deliverable by militarily acceptable techniques, and (5) effective on the target under various field conditions. Tested against these criteria, a comparatively small number of chemical compounds have proved adaptable to military use. Most of those determined to be acceptable are liquids at normal temperature and pressures, a few are true gases, and some are solids.

Some valuable toxic compounds are carried to the target as a liquid fill in a weapon. Upon impact, the liquid is blasted into small droplets, which are quickly transformed into a vaporous cloud.

The G-agents (nerve gases) are toxic both as a vapor and as a liquid. As a vapor, they are lethal upon inhalation and by skin penetration. As a liquid, they are lethal upon direct contamination of the skin.

NERVE GASES.—In 1937 German scientists developed a highly toxic compound which they called Tabun (known to us as GA). In 1938 they produced a compound called Sarin (GB), and in 1944 another called Soman (GF). The Germans were also the first to develop a manufacturing capability in these agents, which were loaded in glass-lined bombs. After Germany's defeat, stocks of nerve gases were captured by the Western powers and by the Soviet Union. A German plant making GA was transported to Russia.

While these agents differ in molecular structure, they all affect man in the same way: they upset the balance between the sympathetic (adrenergic) and the parasympathetic (cholinergic) nervous system. This balance is maintained normally by cholinesterase reacting with acetylcholine, a product of nerve cell metabolism. These agents destroy cholinesterase and thereby permit an accumulation of acetylcholine, which continually stimulates the parasympathetic

TABLE II.—*Symbol, Physiological Action, and Description of Toxic Chemical Agents and the Air Chemical Munitions Using Them as a Fill*

Symbol	*Name*	*Physiological Action*	*Description*	*Air chemical munition using agent as fill*
GB.......	Sarin...	Affects nerves; produces death in a matter of minutes.	A liquid possessing a high boiling point and low freezing point; extremely toxic, with immediate casualty effect. Can kill or disable in very low concentrations over long exposure periods. Odorless. Disseminated as colorless gas cloud in the field. Very toxic as a liquid contaminant.	M34A1 cluster containing 76 M125 bombs; MC-1 750-pound toxic bomb.
GA.......	Tabun.	Same as GB.....	A liquid of high boiling and low freezing point; extremely toxic; with immediate casualty effect. Can kill or disable in very low concentration over long exposure periods; has a faint fruity odor. Can be used as a liquid contaminant in the field or as a colorless gas-cloud.	None.

nervous system. To use a simple illustration, if your finger touches a hot stove, a nerve immediately carries the sensation of pain up your arm to the top of the spinal column. Between the end of the nerve carrying the pain sensation and the nerve carrying the impulse to a muscle (which will cause you to jerk your finger away from the stove), an acetic acid ester (acetylcholine) permits the transmission of the nerve impulse across the space between the nerve ends. Why does your arm stop jerking? Because immediately after the transmission of the nerve impulse, a second chemical, cholinesterase, enters the picture to counteract the acetylcholine. But if you should breathe a toxic G-gas, the cholinesterase would be destroyed and your arm would continue to jerk convulsively. An immediate injection of atropine compound may counteract this condition; otherwise, death follows in a matter of minutes after toxic amounts of the nerve gases have been inhaled.

Some of the characteristics of GA and GB are shown in Table II. The United States has now standardized GB as a war gas.

Incapacitants.—Another type of chemical agent which shows much promise is one that incapacitates but does not kill. Incapacitating agents fall into two general groups: those which produce temporary physical disability such as paralysis, blindness, or deafness; and those which produce temporary mental aberration. Unlike the lethal war gases or the more virulent biological agents, these incapacitants can produce purely temporary effects without permanent damage. In this respect they more nearly resemble the riot control gases or some biological agents which are deliberately not killers. But in another respect they are quite different. They act swiftly, and their arrival may not be heralded by any human senses except as the effects are realized. Drugs tested have no discernible aftereffects, and, depending on dosage, after a few hours or a couple of days the subject is completely recovered.

A cat receiving a psychochemical agent—a chemical which affects the mind—can be so changed in character that it will be in great terror of mice in its cage, cowering and leaping about wildly to keep its distance from the mice (Fig. 50). Troops exposed to one of these agents may not even be conscious of

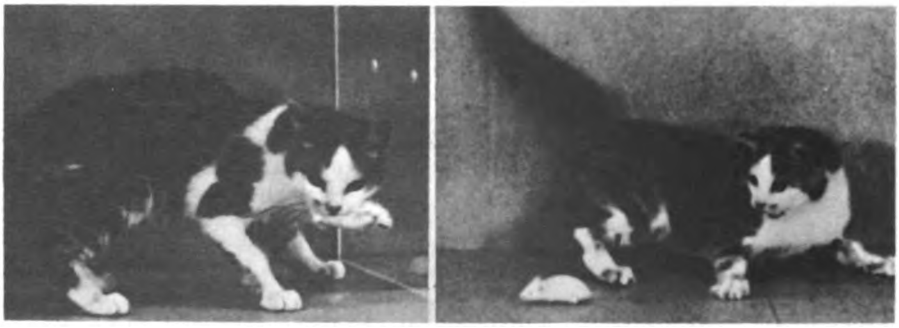


Figure 50. A normal cat (left) behaves abnormally after exposure to a psychochemical (right).

their abnormal condition; their behavior may be so abnormal that they are unable to follow simple commands and perform normal tasks with acceptable accuracy.

Experimental work on incapacitating agents is still at an early stage. A derivative of lysergic acid, LSD 25, is the only mind-affecting psychochemical drug so far announced in this country. Soviet sources have stated that "special interest attaches itself to the so-called psychic poisons (mescaline, methedrine, lysergic acid derivatives) which are now used for simulation of mental disease."

Another approach to temporary incapacitation is the use of a compound which produces an ascending paralysis. With increasing doses, the victim loses first the ability to stand and then the use of the upper extremities. The functions of the diaphragm, however, continue without ill effect. Spontaneous recovery occurs sometime within 24 hours, depending on the size of the dose, with no permanent injury. An antidote, now available for use, reverses the process at will. Although this incapacitant is still in the experimental stage, it has decided possibilities as a chemical agent.

Although some of the incapacitants in gaseous form imply the same logistic problems as the older war gases, others may have the concentration potentialities of the nerve gases. Nerve gas has about one seventy-fifth the weight and bulk of mustard gas with the same potential for incapacitation. Some incapacitating agents can be introduced into a water supply, and resist the efforts of boiling or chlorination as a way to purify the water. Where a nerve gas moves from limited effects to lethal effects by a mere doubling of the dose, some of the incapacitating agents would require a thousandfold increase in the application to be lethal, and therefore truly live up to the promise of only temporary effect.

The incapacitating agents suggest employments where military necessity requires control of a situation, but where there is good reason for not harming the intended target troops. One situation in which this might be desirable would result if enemy troops occupied a nation, and the population could not be segregated from the troops. Then the friendly population and enemy troops could be jointly attacked without producing fatalities. The incapacitating agents also suggest covert uses either to confuse defenses or retaliatory forces, or to affect the rationality of important leadership groups at some particularly crucial point in history.

Toxic Air Chemical Munitions.—One important characteristic of a chemical munition is that it is not dependent upon its point of impact or area of burst for effectiveness against personnel. Immediately upon impact, it forms a gaseous cloud which blankets the target area, searching out the defender wherever he might be—in foxholes, natural shelters, or fortified pillboxes.

The second distinctive characteristic is that the toxic chemical weapon can, by contamination, render an area or position untenable or unusable for varying periods of time. Stated simply, a chemical weapon can be employed so that its primary effects remain on the target long after the weapon itself has been expended.

Toxic air chemical munitions have been developed to utilize the nerve gas GB as a standard fill.

M34–A–1 (1,000-Pound Chemical Cluster).—This munition contains 76 M125 10-pound bombs (Fig. 51), and each of these 10-pound bombs contains

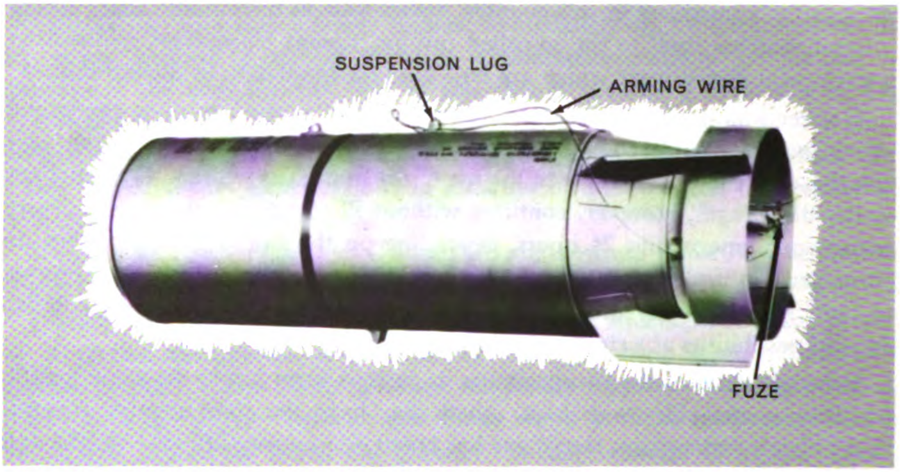


FIGURE 51. The M34A–1, gas bomb, cluster.

about 2.5 pounds of liquid GB. A pair of mechanical air-arming time fuzes are set to function at a predetermined altitude. They detonate a ring of primacord (an explosive in the form of a cord) which is located directly above four striker pins. The force of the detonation of the primacord drives the striker pins into four shotgun-type cartridges. Gas pressure developed by the explosion releases the mechanism holding the 76 bombs inside the cluster casing and, at the same time, ejects the bombs from the casing. Once out of the casing, the individual bombs fall free. Four to five seconds later a parachute, which is released from

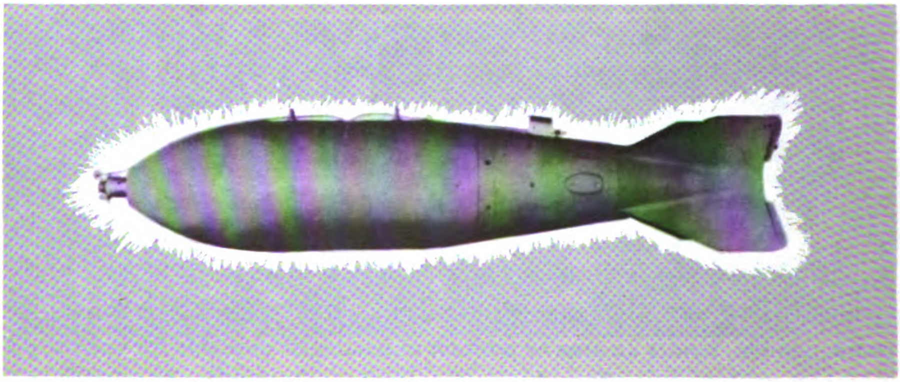


FIGURE 52. The MC–1, 750 pound, low drag, bomb.

the tail of each bomb, acts to stabilize the bomb, arm the fuze, and slow down the descent. The individual bombs burst on impact, releasing liquid GB, which evaporates to form a gas cloud in about one minute. The gas cloud moves downwind.

MC–1 (Toxic Gas Bomb).—This item is a modification of the 750-pound demolition bomb redesigned to accommodate chemical agents (Fig. 52). It can be carried either externally or internally on bomber and fighter-bomber aircraft, and it contains approximately 220 pounds of liquid GB. It can be fuzed electrically or for nose and tail impact.

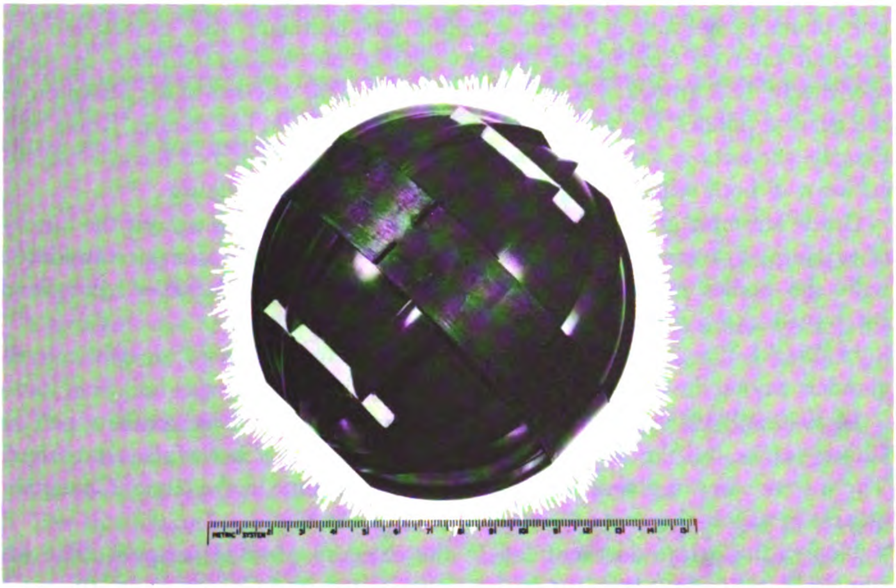


FIGURE 53. One of the several types of bomblets that can be used in dispersing toxic chemicals.

Other munitions recently developed employ small bombs of different shapes, one of which is shown in Figure 53. When released into the air, the bomblets develop lift and become self-dispersing; thus they can be used effectively in the dispersal of toxic chemicals. The use of large numbers of bomblets minimizes the effects of weather and terrain. As these sources of the toxic agent are released in quantities, the individual cloudlets tend to merge and drift, thereby contaminating the target area before they disappear.

With the use of dispensers and warheads, toxic chemicals can cover an area comparable to that affected by a small-yield nuclear weapon. The delivery of these chemicals by spraying from low-flying aircraft would be effective over much larger areas than delivery by bomblets. The difficulty of penetrating heavily vegetated terrain, such as jungle areas, should be considered before deciding on either spray or bomblets.

BIOLOGICAL WARFARE

There have been new developments in explosive bombs, aircraft armament, and chemical weapons, but in most cases these developments have been arrived at only after long operational experience. Although nuclear weapons are relatively new, we know enough about them to be fully aware of their cataclysmic destructive powers. In the case of biological warfare, we have considerably less experience and knowledge.

Biological warfare is the intentional use of living organisms, or their toxic products, to cause disease or death in man, animals, or crops. Although biological warfare is not a new idea, it is assuming greater importance in military planning because of recent scientific advancements and increased international interest. Communist charges against the United Nations, or more specifically, U.S. troops in Korea, brought biological warfare to the attention of the general public. The fact that biological warfare was not used in Korea and that the accusations were completely false has in no way lessened the interest and curiosity of both military and civilian segments of our population.

Crude attempts at biological warfare have been made throughout the history of warfare. For example, pollution of water sources was often accomplished with the bodies of dead animals; and the bodies of plague victims were catapulted into besieged cities.

In World War I the Germans employed bacteria to start an epidemic of glanders among the horses of the Rumanian cavalry.

In 1940 and 1941 it was reported that plague-infected fleas were dropped on Chinese cities, but the validity of these reports has never been fully established. There were cases of plague which occurred at this time in the city of Changteh, an area in which plague is not endemic.

Biological warfare does not fall in the category of tried weapons. The instances of its use have been too few, too specialized, and too poorly documented. In fact, the feasibility of biological warfare as a weapon has often been questioned. Between the two World Wars, this subject was treated in many articles, most of which expressed doubt as to its value as a weapon. However, as a result of field trials under various conditions, much has been learned in recent years about the effectiveness of diseases disseminated in an aerosol cloud. There is no longer any doubt that very large areas could be covered with agents which would infect large percentages of the target population. The techniques for mass production of these agents are known.

Biological warfare can produce effects ranging from relatively mild illness to death. The severity of the illness would depend on the agent used and the resistance of the host to that agent. An incapacitating illness might be the aim of biological warfare in antipersonnel attacks. This would tax medical and economic facilities more severely than would a large number of fatalities. In antianimal and anticrop attacks, death and destruction are preferable. In all forms of biological warfare a psychological reaction could be expected, and every effort would be made to exploit it.

Biological agents are designed to cause a primary infection from an aerosol cloud. Secondary spread from an infected person to noninfected persons within the target area is not likely.

Mass immunization of target populations may not affect the numbers of casualties that are produced. Immunization may be nullified by massive doses of the agent or by artificial mutation of the disease to create a strain to which there is little immunity.

Biological warfare agents include micro-organisms, their toxic products, and certain chemical compounds. Only a few, some mentioned briefly in this section, meet the military requirements established for biological warfare agents. These requirements include capability of infecting a host, economical production in adequate quantities, and stability in storage. Other desirable properties are difficulty of detection, capability of producing rapid and widespread disease, difficulty of protection and immunization, entrance through more than one portal, and a short incubation period.

Employment of Biological Warfare

Biological agents produce no immediate physiological reaction, nor can they be detected by the physical senses.

Casualties can be produced with small amounts of the biological agent. This characteristic gives biological agents the capability of covering large areas with small munition expenditures.

The availability of biological agents that can produce deaths or varying degrees of incapacitation among target personnel permits the commander to select an agent that will produce the desired military effect.

The incubation period of biological agents results in a lag period of several days before casualties are produced. This time interval can be coordinated with planned future operations.

EFFECTS OF WEATHER.—The dissemination of biological agents by moving clouds is affected by meteorological conditions in much the same manner as the cloud travel of chemical agents is affected. However, certain meteorological conditions have a particular effect upon the cloud travel and employment of biological agents.

Windspeed.—Biological agents with a high decay rate can be employed effectively at high windspeeds (10 to 20 miles per hour). At these higher windspeeds, biological agents are exposed to adverse environmental conditions for a shorter time, and greater area coverage can be obtained during the decay period.

Sunlight.—Exposure to sunlight will increase the decay rate of a biological agent aerosol, thereby reducing its area coverage. For this reason, in addition to the existence of an unfavorable temperature gradient on sunny days, the preferable time for a biological attack is at night.

EFFECTS OF TERRAIN.—Terrain characteristics similarly affect the dissemination of biological and chemical agents by cloud movements. Ground contamination following a biological aerosol attack is not generally considered a

hazard to troops traversing or occupying the terrain. A few casualties may be produced by secondary aerosols that are formed by marching men and vehicular traffic, or by contact with ground contamination.

CONCEPTS OF EMPLOYMENT.—The effectiveness of a biological attack depends on a number of factors relating to the agent-munition systems. These factors—storage stability, munition dispersion, aerosol decay rate, required time to produce casualties, and concealment of the attack—also affect the selection of the method of employment of specific munitions.

Methods of Employment.—The two general methods of employing biological agents are on-target and off-target attacks. In an on-target attack the biological agent is released directly on the target area. This method provides the maximum degree of operational control. Since the agent is distributed more or less uniformly over the target area, wind direction and velocity are not critical factors.

In off-target attack, the biological agent is released at a substantial distance upwind. Once released, the agent is transported over the target area by the wind. The reliance on wind direction for target coverage requires the release of the agent in such a pattern that a wind direction anywhere within a 45° sector will effectively carry the agent over the target area.

Agent Selection.—The selection of a biological agent to be used against a specific target will be influenced by certain significant characteristics of the target.

Target Characteristic	*Characteristic of Effective Agent*
Close to friendly forces	High decay rate.
Large area target	Low decay rate.
Primarily military target	Lethal.
High percentage of friendly civilians	Incapacitating.

Munition Selection.—Biological munitions fall into two categories. One type, which produces an aerosol in a line and relies on the wind to carry the agent over the target, is referred to as a "line source." The other type, which is scattered at random over the target area, is referred to as "self-dispersing." The selection of these munitions will be influenced by certain characteristics of the target.

Target Characteristic	*Characteristic of Effective Munition*
Large areas	Self-dispersing.
Poor biological-chemical warfare discipline; inadequate alert system	Self-dispersing.
Wind direction unknown	Self-dispersing.
Wind direction known (within 45°)	Line source.
Off-target attack preferred or required	Line source.
Small area	Line source.

The self-dispersing munition can be generally the same type of small bomblet as that used to disperse chemical agents and it can be carried in the same dispenser as chemical agents. Line source refers to a low-level spray attack by fighter or larger aircraft as well as by the use of bomblets or bombs dropped one after another throughout a long flight path.

Offensive Employment.—Enemy targets in the vicinity of the line of contact will not normally be engaged with biological agents because of the delay in producing casualties. Biological agents may be employed, in support of offensive operations, on relatively deep targets such as Army reserves and airbases within an enemy country where a delay in casualty effects will be acceptable.

Defensive Employment.—The length of time that a unit plans to defend a position will determine the areas where biological agents can be employed. If the defense of a position will last longer than the incubation period of the agent to be used, targets closer to the line of contact may be engaged. Operations that are characterized by successive delaying positions will present targets in areas up to and including the line of contact. Biological warfare casualties may not be produced in time to affect the defense of each delaying position, but casualties will probably be produced by the time friendly forces initiate offensive operations. In this type of operation, it is difficult to obtain accurate intelligence about targets that are dispersed over large areas. Biological agents can effectively engage widely dispersed targets because of the large areas that can be covered with little effort and small expenditure of munitions.

Special Operations.—Decay of biological agents is not as rapid in arctic areas as in temperate or tropical areas. Area coverage capability is increased and the need for refrigerated storage of the munitions is reduced. Certain factors that pertain to chemical warfare in arctic areas, such as masking efficiency, cloud behavior, and munition efficiency, apply to biological warfare as well.

Planning for the employment of biological agents in jungle areas must include considerations of prevailing low windspeeds and high temperatures. These two characteristics reduce area coverage capability and increase the expenditure of biological munitions.

Enemy forces that are located on isolated islands are ideal targets for biological agents. The agents must be employed sufficiently in advance of the amphibious landing to allow time for the production of casualties. Troop safety is no problem because of the isolated target. Biological agents should be employed at the start of the preparatory attacks to enhance the element of surprise and to obtain maximum casualties at the time of the landing.

Defense Against Biological Warfare

Protection against biological warfare is of two types: immunization and use of protective devices. Immunization of personnel and animals would not significantly alter the outcome of a biological warfare attack. Some writers believe much might be done to determine beforehand those disease organisms which might logically be used, and undertake mass immunization measures before an attack, possibly by means of aerosol sprays. If protective devices are used at the time of attack, they are highly effective in protecting personnel from biological agents. Protective devices include special clothing, masks, and collective protectors (devices for rendering enclosures safe for occupants). Clothing can

FIGURE 54. An infrared device for detecting air contaminants as far as one quarter of a mile away has been developed by U.S. Army Chemical Corps.

be made impermeable to particles or droplets. If gas masks are used properly, they provide adequate protection for the respiratory system. Collective protectors that work on the same principles as gas mask canisters could protect a room or building so that the occupants would not have to wear individual protective equipment.

Detection of agents is a major problem in defense against biological warfare. (Fig. 54) An overt attack might be very easy to detect; however, even though

the munitions are observed functioning it must be realized that infection of the target population has already begun. A covert attack might not be detected at all. The first indication might be an increased incidence of disease. Regular examination of food, water, and air might give early indications, but would be an expensive undertaking. There is no easy solution to this problem.

Once a biological attack is detected, immediate decontamination is necessary. Food and water can be made sterile by boiling. Although food in cans will not be contaminated, containers should be sterilized before opening. If the attack has been made with an aerosol cloud, it may also be necessary to decontaminate buildings, vehicles, clothing, and even streets. Effective sterilizing agents include formalin, phenol, and sodium hypochlorite. Boiling of cotton clothing would also be effective.

The aim of all the suggested defense measures is to prevent the spread of diseases. The last line of defense would be medical treatment of the afflicted. We must remember, however, that an abnormally heavy demand upon doctors, nurses, hospitals, and medical supplies would tax resources severely and would in itself be one of an enemy's objectives.

Biological Agents Affecting Man

Diseases which could incapacitate or destroy man if used in biological warfare include those caused by bacteria, viruses, protozoa, and toxins of microbic, vegetable, or animal origin.

BACTERIAL DISEASES.—Among bacteria that might possibly be used against man are those producing anthrax, undulant fever, tularemia, and melioidosis.

Anthrax, a disease with high mortality rate, is associated with animal infections or handling of infected hides and furs. Local infection is characterized by carbuncles; lung or general infection, resulting from scratches or inhalation, is almost always fatal. Antianthrax serum confers some passive immunity.

Undulant fever, also called brucellosis, is also associated with animals, and is typically contracted by ingestion of contaminated milk or other dairy product. Infection may also result from inhalation or accidental inoculation. Immunization methods are unsatisfactory for man.

Tularemia, also known as rabbit fever and deer fly fever, is likewise associated with animals, usually those in the wild state. While not transmitted directly from man to man, bites of infected flies and ticks may transmit the disease, or it may be contracted by direct contact with the organism. Enemy attack might therefore be direct and indirect.

Melioidosis, also known as Whitmore's disease, is primarily a rodent's disease similar to glanders. In man it is almost always acute and rapidly fatal. Contamination may result from eating contaminated food, or following bites of rat fleas. No vaccine has been developed. It could possibly be spread by droplets in cold climate.

RICKETTSIAL DISEASES.—Rickettsial micro-organisms, while bacteriumlike, are believed by some to be of protozoan nature. Among diseases of this type

which might be adaptable for biological warfare are Rocky Mountain spotted fever and Q-fever. Common sources of infection are ticks or by direct contact with the micro-organism. This implies both direct and indirect possibilities of attack against human beings. Q-fever may also be transmitted via milk or flesh from diseased animals, or from dust-laden air. Q-fever is relatively noncontagious.

Viral Diseases.—Smallpox, yellow fever, and encephalitis and encephalomyelitis are among the virus-produced diseases that may be used in biological warfare. Smallpox is effectively combated by vaccination, but revaccination every 3 years is advisable to maintain minimal immunity. Yellow fever, transmitted ordinarily by the bite of mosquitoes, is controlled by mosquito control. Active immunization may protect for 4 years or longer. Encephalitis and encephalomyelitis both produce similar sicknesses. Five or more types are produced by as many viruses. Wild and domestic birds are the principal sources of mosquito infection of the virus types occurring in the United States, and mosquitoes in turn transmit the disease to animals and human beings. Some types can be transmitted to man directly from animals.

Protozoic Diseases.—While serious diseases such as amoebic dysentery, African sleeping sickness, and malaria are produced by protozoa, this type of disease is the least likely to be used in biological warfare due to difficulty of production and transmission of it.

Diseases Produced by Toxins.—Toxins are any poisonous substances of microbic, vegetable, or animal origin. One of these will be mentioned here to illustrate possible use of toxin. The most poisonous substance known is of bacterial origin—botulinum, occurring in at least five types. In man, botulism results from eating certain types of spoiled and contaminated food. Conceivably, toxins similar to this could be administered directly by an enemy, without resorting to bacterial infection of food.

Biological Agents Affecting Animals

The primary purpose of biological attacks against animals would be to reduce man's food supply, draft power, and transportation facilities. Agents are easily transmitted from one animal to another or from herd to herd. For that reason, epizootics (epidemics of animal populations) would be more easily established than epidemics among man. Some experts believe biological warfare directed against domesticated animals would ultimately be more effective than against man himself, provided that such warfare had any characteristics of long-term attrition.

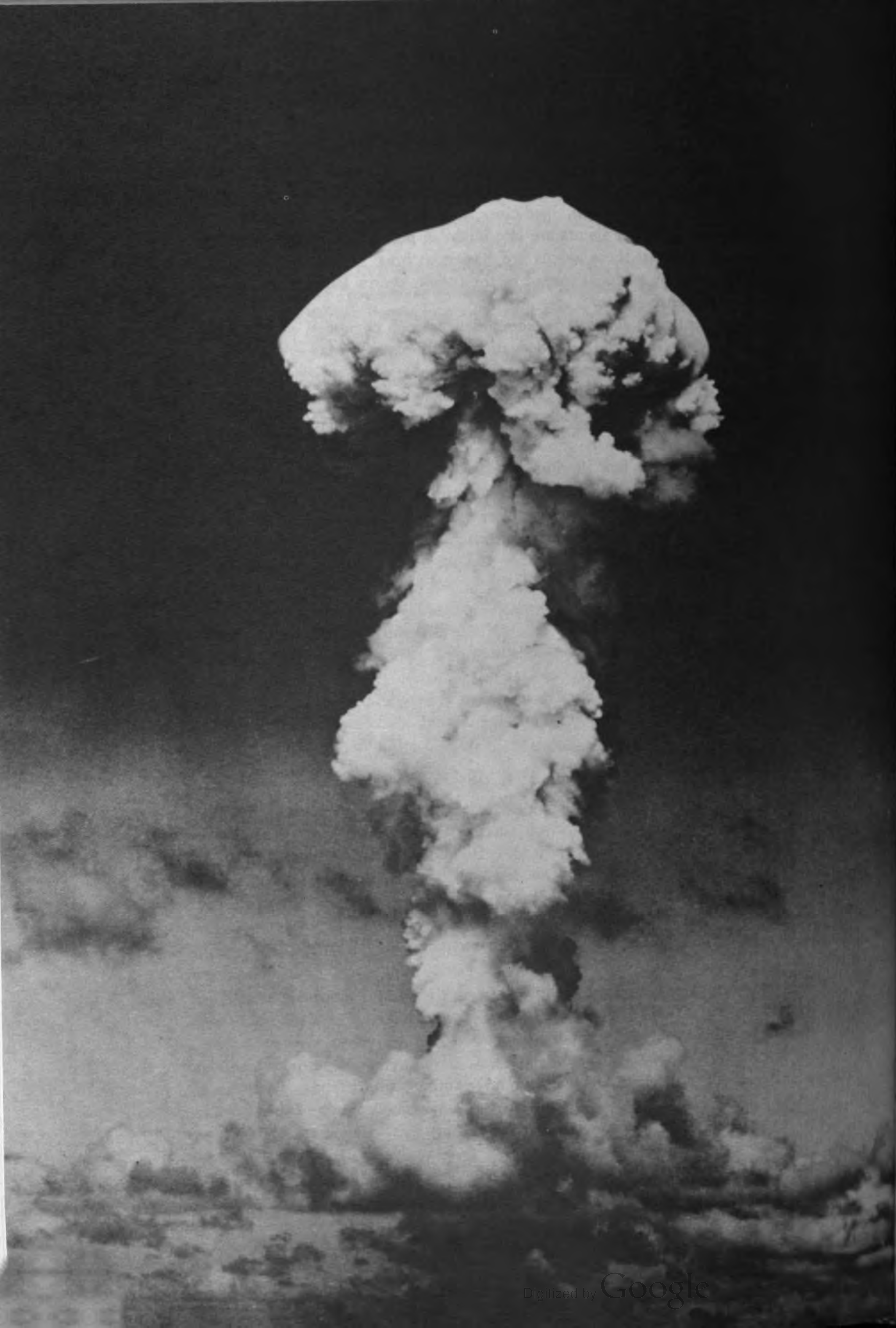
Diseases mentioned primarily in this type of warfare are foot-and-mouth disease, rinderpest, hog cholera, and fowl plague. Immunization procedures are effective against rinderpest and hog cholera, but not against fowl plague and foot-and-mouth disease; animals suffering from the latter disease must be slaughtered, and exposed animals quarantined to bring the disease under control. All the above diseases may be transmitted by contaminated food, and all are highly contagious to other animals.

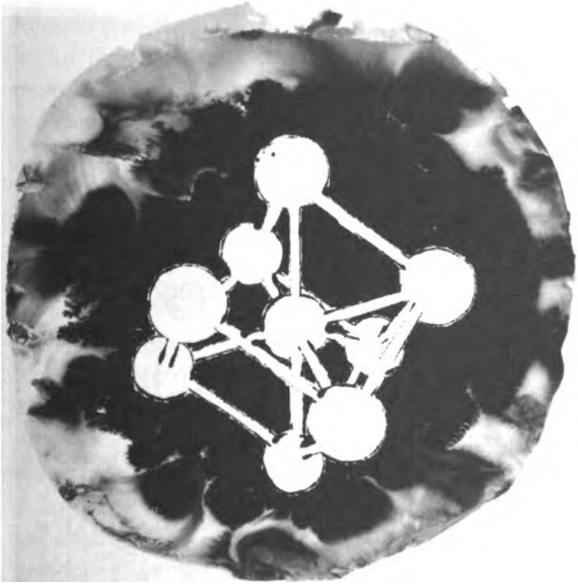
Anticrop Agents

Both biological and chemical attack may be made against crops. Crop destruction would affect the food supply of both man and domestic animals, and destroy sources of essential oils, medicines, and industrial raw products.

Among the biological agents are late blight of potatoes, stem rust of cereals, and blast of rice. All these agents are classed as fungi. The plants mentioned may be infected by physical spread of the fungus spores. Control methods are similar, but expensive.

Nonliving anticrop agents are exemplified by such chemicals as 2,4-D (2,4-dichlorophenoxyacetic acid), used against broad-leaved plants such as cotton, beans, sugarbeets, sweet potatoes, flax, Irish potatoes, and soybeans. It may be applied by spraying or dusting. Remarkably small applications are effective. Once applied, and once symptoms of injury appear, plantings cannot be treated.





CHAPTER 7

NUCLEAR ENERGY

and the Effects of Nuclear Weapons

To understand the practical application of nuclear energy, as a weapon, one must first understand some elementary principles of nuclear energy. This chapter will review these principles briefly before describing the types and effects of nuclear explosions. The latter part of the chapter will consider radiological warfare as a part of CBR warfare, the term and concept of which were introduced in the preceding chapter.

ELEMENTARY PRINCIPLES OF NUCLEAR ENERGY

The nuclear age for the United States began secretly in the fall of 1939, when certain scientists asked Dr. Albert Einstein to inform President Franklin D.

◀ **Able day at Bikini, 1 July 1946.**

(Figure to the left of the symbol is the atomic number of the element; figures shown below each element represent the mass numbers of the isotopes; mass numbers shown in boldface represent radioactive isotopes)

		GROUP 0	GROUP I		GROUP II		GROUP III		GROUP IV		GROUP V		GROUP VI		GROUP VII		GROUP VIII		
Family:			A	B	A	B	A	B	A	B	A	B	A	B	A	B			
Period 1	Series 1		1 H HYDROGEN 1 2 **3**																
2	2	2 He HELIUM 3 4	3 Li LITHIUM 6 7		4 Be BERYLLIUM 9		5 B BORON 10 11		6 C CARBON 12 13			7 N NITROGEN 14 15		8 O OXYGEN 16 17 18		9 F FLOURINE 19			
3	3	10 Ne NEON 20 21 22	11 Na SODIUM 23		12 Mg MAGNESIUM 24 25 26		13 Al ALUMINUM 27		14 Si SILICON 28 29 30			15 P PHOSPHORUS 31		16 S SULFUR 32 33 34 36		17 Cl CHLORINE 35 37			
4	4	18 A ARGON 36 38 40	19 K POTASSIUM 38 39 **40** 41		20 Ca CALCIUM 40 42 43 44 46 48		21 Sc SCANDIUM 45		22 Ti TITANIUM 46 47 48 49 50		23 V VANADIUM 51		24 Cr CHROMIUM 50 52 53 54		25 Mn MANGANESE 55		26 Fe IRON 54 56 57 58	27 Co COBALT (57) 59	28 Ni NICKLE 58 60 61 62 64
	5			29 Cu COPPER 63 65		30 Zn ZINC 64 66 67 68 70		31 Ga GALLIUM 69 71		32 Ge GERMANIUM 70 72 73 74 76		33 As ARSENIC 75		34 Se SELENIUM 74 76 77 78 80 82		35 Br BROMINE 79 81			
5	6	36 Kr KRYPTON 78 80 82 83 84 86	37 Rb RUBIDIUM 85 **87**		38 Sr STRONTIUM 84 86 87 88		39 Y YTTRIUM 89		40 Zr ZIRCONIUM 90 91 92 94 96		41 Nb NIOBIUM 93		42 Mo MOLYBDENUM 92 94 95 96 97 98 100		43 Tc TECHNETIUM **96 99 101**		44 Ru RUTHENIUM 96 98 99 100 101 102 104	45 Rh RHODIUM 103	46 Pd PALLADIUM 102 104 105 106 108 110
	7			47 Ag SILVER 107 109		48 Cd CADMIUM 106 108 110 111 112 113 114 116		49 In INDIUM 113 115		50 Sn TIN 112 114 115 116 117 118 119 120 122 124		51 Sb ANTIMONY 121 123		52 Te TELLURIUM (120) 122 123 124 125 126 128 130		53 I IODINE 127			
6	8	54 Xe XENON 124 126 128 129 130 131 132 134 136	55 Cs CESIUM 133		56 Ba BARIUM 130 132 134 135 136 137 138		57-71 RARE EARTHS[a]		72 Hf HAFNIUM 174 176 177 178 179 180		73 Ta TANTALUM 181		74 W WOLFRAM 180 182 183 184 186		75 Re RHENIUM 185 187		76 Os OSMIUM 184 186 187 188 189 190 192	77 Ir IRIDIUM 191 193	78 Pt PLATINUM 192 194 195 196 198
	9			79 Au GOLD 197		80 Hg MERCURY 196 198 199 200 201 202 204		81 Tl THALLIUM 203 205		82 Pb LEAD 204 206 207 208		83 Bi BISMUTH 209		84 Po POLONIUM **210**		85 At ASTATINE **211 216 218**			
7	10	86 Rn RADON **222**	87 Fr FRANCIUM **223**		88 Ra RADIUM **225 226**		89 Ac ACTINIUM **225 227**		90-98 RARE EARTHS[a]										

[a]Rare Earths fit into the periodic table as follows:

57 La LANTHANUM 139	**58 Ce CERIUM 136 138 140 142**	**59 Pr PRASEODYMIUM 141**	**60 Nd NEODYMIUM 142 143 144 145 146 148 150**	**61 Pm PROMETHEUM 144**	**62 Sm SAMARIUM 144 147 148 149 150 152 154**	**63 Eu EUROPIUM 151 153**	**64 Gd GADOLINIUM 152 154 155 156 157 158 160**
65 Tb TERBIUM 159	**66 Dy DYSPROSIUM 158 160 161 162 163 164**	**67 Ho HOLMIUM 165**	**68 Er ERBIUM 162 164 166 167 168 170**	**69 Tm THULIUM 169**	**70 Yb YTTERBIUM 168 170 171 172 173 174 176**	**71 Lu LUTECIUM 175 176**	

90 Th THORIUM 229 232	**91 Pa PROTOACTINIUM 231**	**92 U URANIUM** 233 234 235 238 239	**93 Np NEPTUNIUM 238 239**	**94 Pu PLUTONIUM 238 239**	**95 Am AMERICIUM 241**	**96 Cm CURIUM 241 242**	**97 Bk BERKELIUM 244**	**98 CALIFORNIUM 244**

FIGURE 55 Table of elements

Roosevelt of their belief that the release of nuclear energy was possible. According to them, nuclear energy could be freed in either a controllable reaction to provide a source of continuous energy, or in a rapid reaction to produce a nuclear explosion. What knowledge and experimental data led them to this conclusion?

This section presents some background of the search for knowledge before nuclear energy could be released.

Theory of the Structure of Matter

For many centuries the idea prevailed that the material universe was composed of a very few basic elements which, in various combinations, produced the wide variety of materials. Gradually, early scientists began to isolate and identify more of the true basic elements. Once enough elements were known, together with their characteristics, the stage was set for learning a great deal more about the material universe. For example, it was possible to predict that the natural elements would total 92.

In 1869 the Russian chemist Dmitri Mendeleev proposed his well-known periodic table of elements. He based it upon the idea that in the orderly progression from the lightest to the heaviest element, a periodicity—a recurring sequence—appears in the chemical properties. In Figure 55 the atomic numbers of the elements are shown to increase in a progression from hydrogen to helium, to lithium, and so on. Also, when they are arranged in this order, the elements in any one vertical column show a similarity of chemical properties. Mendeleev was so sure of this theory that, where there was yet no element identified for a particular atomic number, he left a blank in the table and predicted that the mass number of the element was between the mass number of the preceding and succeeding elements. Further, he defined the chemical properties, in general, as being similar to the other elements in the same column. As the ability to isolate and determine chemical properties improved, the blank spaces left by Mendeleev in the original periodic table were gradually filled in until all of the 92 were identified.

Let us review briefly certain fundamentals of chemistry and physics which are necessary steppingstones to an understanding of Mendeleev's periodic table and of nuclear science.

An element is a substance, like iron, carbon, silver, and oxygen, which cannot be chemically reduced to, or built up from, a simpler substance. Its smallest unit is called an atom, which for a long time was believed to be indivisible.

Two or more elements may exist in a fixed ratio in a compound, the smallest unit of which is a molecule. Water, for instance, is a compound. A molecule of water consists of two atoms of hydrogen and one of oxygen. We can also speak of free, uncombined atoms as molecules. Both molecules of compounds and uncombined molecules can exist in a mixture, such as the air we breathe, which consists of about 78 percent nitrogen and about 21 percent oxygen, plus small amounts of other gases, all intermingled as free molecules. There is, thus, no such thing as a molecule of air.

The formation or division of molecules is frequently accompanied by a release

of energy, usually in the form of heat. Sometimes, as in the case of iron combining with oxygen to form rust, the reaction is so slow that the release of energy is imperceptible. On the other hand, an excitation applied to a mixture of hydrogen and oxygen can stimulate these two elements to combine, forming water so rapidly that the release of energy produces a flash and bang. In this rapid chemical reaction some potential energy of the hydrogen and oxygen atoms is released as kinetic energy, much of which is dissipated in the air.

The fundamentals outlined represent good 19th-century science, and they are still workable and valid. Modern discoveries have gone beyond them but have not refuted them.

The idea that the universe is composed of less than a hundred elements (building bricks or atoms) is consistent with man's intuitive belief in the simplicity of nature. In the 1890's scientists wondered if matter could be further reduced. They asked: Are not the elements, the atoms themselves, composed of different combinations of even more fundamental building bricks? The search for the answer to this question eventually began to bear fruit.

Two particles were identified as being much smaller than any of the atoms of elements and as having no properties related to the elements from which they came. They are called electrons and protons.

The electron is a particle with a negative electric charge; the proton, a particle with a positive electric charge. When protons are placed near protons, or electrons near electrons, the similar particles repulse each other. But when electrons are placed near protons, they are attracted. In addition to having electrical properties, these particles have size and mass. Although the electrons and protons have the same quantity of electrical charge, their masses differ considerably. The proton has been proved to have approximately 1,832 times more mass than the electron.

The Concept of Atomic Structure

Electrons and protons exist in different quantities and arrangements to form different elements. Of the several theories explaining the arrangement of protons and electrons within the various elements, only one has stood the test of time—that of Dr. Niels Bohr, a Danish physicist.

With the atom defined as the smallest particle of an element which still retains the chemical characteristics of that element, Dr. Bohr proposed that the atom is composed of protons and electrons in an arrangement similar to that of the sun and its planets. The sun is a massive central core around which the much smaller planets move in orbits. The atom is thought to be composed primarily of a central core, relatively small but relatively heavy, called a nucleus. Around this core much lighter bodies, the electrons, orbit (Fig. 56). It is believed that the atom is normally electrically neutral; therefore the number of protons within the nucleus is equal to the number of orbiting electrons.

Experiments have indicated that there are limits to the number of electrons in one orbit, as well as to the number of qrbits. Each element is composed of

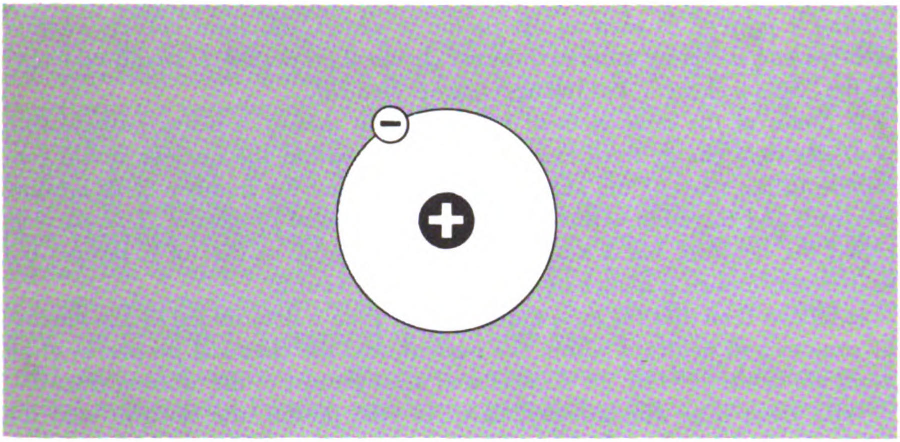


FIGURE 56. Structure of the hydrogen atom, consisting of one proton in the nucleus and one electron in the orbit.

atoms which have a specific number of protons and electrons. These electrons circle the protons in definitely arranged orbits, just as the earth travels in one orbit around the sun, and the planet Mars, in another.

In the progression from the element hydrogen, which has 1 proton in the nucleus and 1 orbiting electron, to the element uranium, which has 92 protons within the nucleus and 92 orbiting electrons, the mass of the atoms, and therefore the mass of the element, increases. With changes in the number of orbiting electrons, there are changes in chemical properties. (Since the mass of the proton is 1,832 times that of the electron, the electron contributes only a negligible amount to the mass of the atom.) The masses of each element were related to a common standard, initially hydrogen (atomic weight, 1.00000), since it is the lightest element. Later the standard was changed to oxygen, since it is the most abundant element and combines readily with most other elements. The atomic weight of oxygen was taken as 16.00000, or about 16 times that of hydrogen.

If it is true that only protons and electrons constitute atoms, there could not be an element with a fractional atomic weight, such as 85.48. It was difficult for the theorists to explain why atomic weights differed by more than one unit if each succeeding element contained an increase of a single proton and electron pair. Experience has revealed, however, that elements with fractional atomic weights do exist. A theory explaining this apparent discrepancy later proved to be correct.

If, in nature, atoms of a particular element appear with different masses—some with a mass of 10.016 and some with a mass of 11.013, for example—and if these atoms were mixed in the proper proportion, it would be possible to have an element with an apparent atomic mass of 10.82. To explain how an element could be composed of atoms with different masses, a new elemental particle must be present.

It is not possible to increase the mass of an atom of a particular element by adding a proton. As soon as the proton is added, the atom collects another electron and therefore assumes different chemical properties. It would no longer be the original element, but the next heavier element.

If atoms of the same element have different masses, a heavy particle with zero electrical charge must exist. This particle within the nucleus would contribute to the mass of the atom without modifying the number of its orbiting electrons and therefore without changing its chemical properties. This particle, called the neutron, has a mass approximately equal to that of a proton, but as its name implies, it is uncharged electrically, or neutral.

It follows then that the mass number of an atom is determined by the number of protons and neutrons within the nucleus, and the chemical properties of an atom are determined by the number and arrangement of the orbiting electrons.

With these three fundamental particles—the proton, the electron, and the neutron—the structure of elements is more easily explained. Although all the nuclei of a given element contain the same number of protons, they may have different numbers of neutrons. The resulting atomic species, which have identical atomic numbers but which differ in their masses, are called isotopes of the particular element. Argon, for example, has atoms with mass numbers of 36, 38, and 40. The atoms are all isotopes of the element argon. It has been found that most elements have atoms of different masses and therefore occur in nature in two or more isotopic forms. The various isotopes of hydrogen are shown in figure 57. An understanding of the existence and composition of isotopes was necessary before the nuclear bomb could be produced.

Radioactivity

Another important contribution to the knowledge leading to the nuclear bomb was made in 1896 by the French physicist Henri Becquerel. His dis-

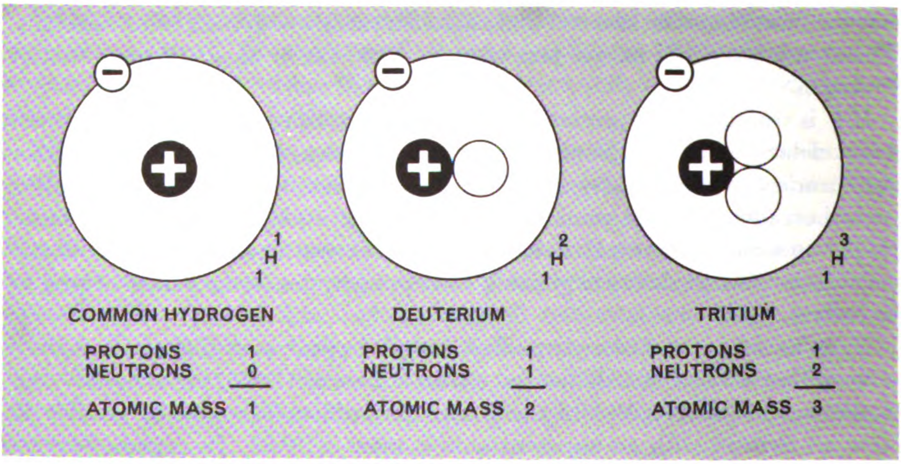


FIGURE 57. Isotopes of hydrogen.

covery of natural radioactivity is reputed to have been made in the following manner. He was investigating the relation between sunlight, the phosphorescence of some salts of uranium, and a photographic plate. When he was ready to perform the experiment, he exposed the plate to sunlight although the day was cloudy. The next day also was cloudy, but again he exposed the plate to sunlight. Each night he carefully wrapped the photographic plate and placed it, with the uranium salts, in his desk drawer. He then decided to develop the plate, expecting to find only a faint image because there was so little sunlight. Instead, the developed plate indicated a very heavy exposure. He then placed uranium salts near another wrapped photographic plate. As before, when the plate was developed, it appeared to have been heavily exposed.

NATURAL RADIOACTIVITY.—Becquerel's experiment led to the discovery of natural radioactivity. Further experiments proved that there were particles and energy emanating from radioactive elements. The particles were called alpha and beta particles, and the energy, gamma rays. By allowing these particles and rays to pass through a magnetic and electric field, it was possible to learn something about their nature. The alpha particles were found to be fairly massive and to have a positive electrical charge, whereas the beta particles were found to be very light and to have a negative charge. The gamma rays were not influenced by the magnetic or electric field and were therefore assumed to be electromagnetic in nature, similar to visible light.

Later experiments proved that the alpha particles are the nuclei of helium atoms (Fig. 58), being composed of two protons and two neutrons, with no orbit-

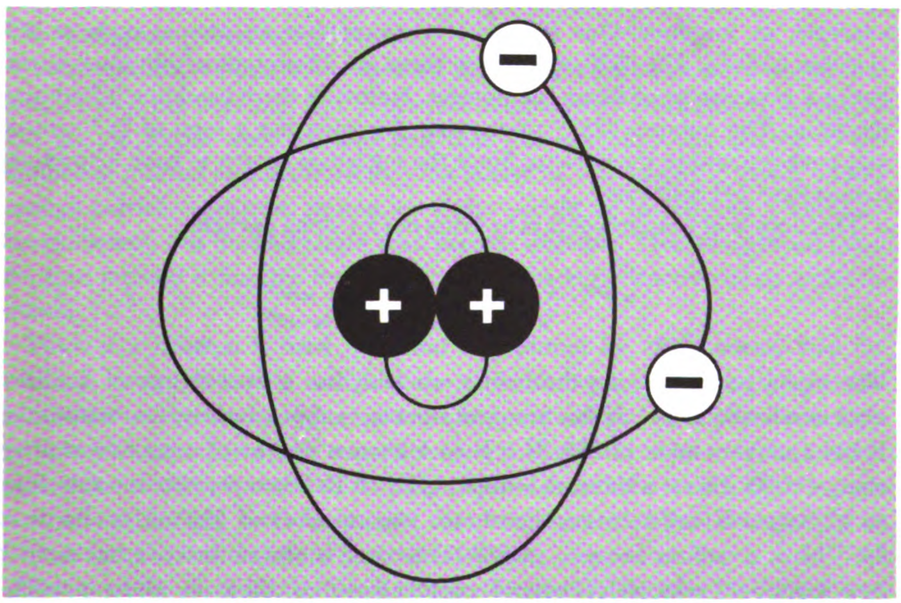


FIGURE 58. Helium atom, showing two orbital electrons and the nucleus consisting of two protons and two neutrons.

ing electrons at the time of emission. The beta partices were proved to be the fundamental negative particles of electricity. the electron. Gamma rays, known to be electromagnetic rays, are similar to radio waves, visible light, and X-rays, with a major difference: gamma rays have a much higher frequency (Fig. 59).

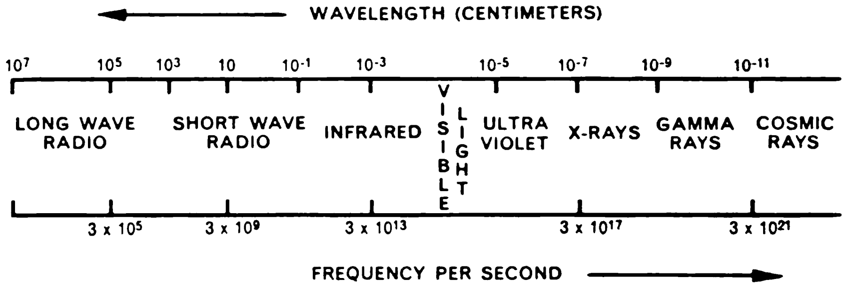


FIGURE 59. Simplified electromagnetic spectrum.

It was found that certain isotopes of some elements are not stable (Fig. 55) and modify their nuclear structure by shooting out a particle. Some of these nuclei fire an alpha particle; others, a beta particle (electron). The atom appears to gain an additional proton by this process, and a transmutation of the element results.

Several radioactive decay series have been isolated and identified, as for example, in uranium. One isotope of uranium has an atomic mass of 233 (written ${}_{92}U^{233}$). The "92" means that there are 92 protons within the nucleus, hence a plus charge of 92 on the nucleus. Normally there would be 92 orbiting electrons. The number "233" means that the atom has a total of 233 protons and neutrons within the nucleus. Since the nucleus is known to have 92 protons, it must have 141 neutrons.

This isotope of uranium decays by firing out an alpha particle:

$$
\begin{array}{ccccccc}
{}_{92}U^{233} & \rightarrow & {}_{90}Th^{229} & \rightarrow & {}_{88}Ra^{225} & \rightarrow & {}_{89}Ac^{225} \\
 & \searrow {}_{2}\alpha^{4} & & \searrow {}_{2}\alpha^{4} & & \searrow {}_{-1}\beta^{0} &
\end{array}
$$

The alpha particle, being the helium nucleus, has a plus charge of 2 and a mass number of 4: ${}_{2}\alpha^{4}$. If this uranium atom loses approximately four mass units, it has a mass number of 229. If it then loses two positive charges, it has a net charge of 90. This is a thorium isotope: ${}_{90}Th^{229}$. This isotope, also unstable, loses an alpha particle. The atom then has a mass number of 225 and a charge of 88. This is a radium isotope: ${}_{88}Ra^{225}$. This atom is also radioactive but emits a beta particle (negatively charged particle) rather than an alpha particle. Since the emission of a beta particle does not affect the mass number, the mass number of the atom remains 225, but the charge changes from 88 to 89, since

giving up a negative charge has the same effect as adding a positive charge. This element is actinium, which is also unstable. This atom continues losing particles and modifying itself into new elements until it reaches an isotope of lead, which is stable.

The rate of each of these processes of radioactivity is defined in terms of the amount of time necessary for half of the atoms present to be transmuted. This time is called the half life. If there are 1 million atoms of uranium $_{92}U^{233}$ present, half of them will transmute themselves into thorium in one half life. The actual half life for the uranium isotope is 162,000 years. This means that 1 pound of this isotope of uranium will, in 162,000 years, be reduced to only one-half pound of $_{92}U^{233}$. The half life of thorium ($_{90}Th^{229}$) is 7,000 years; the half life of radium ($_{88}Ra^{225}$), 15 days; and the half life of actinium ($_{89}A^{225}$), 10 days.

At times an excited atom emits a particle, and in addition releases energy in the form of a gamma ray. An excited atom may also release energy in the form of a gamma ray without emitting a particle. In natural radioactivity, alpha and beta particles and gamma rays can be detected and checked against a decay series similar to the one described.

When it was known that natural radioactive elements release energy, the possibility of using these elements as a source of power was considered. But there would have to be an increase in the rate at which these elements release energy if they were to provide power. A series of experiments attempted to modify the half life of natural radioactive elements. The half life remained constant under all conditions, including those of extreme temperature, strong magnetic fields, and strong electric fields. It became apparent that this method of obtaining energy was not practical.

Artificial Radioactivity.—Since no means were found to speed up natural radioactivity, the next step was to produce radioactivity artificially. It appeared that certain nuclei were unstable and that this instability was related to the number of protons and neutrons they contained. It was suggested that if a basic nuclear particle—neutron, proton, or alpha—could be forced into a normally stable nucleus, this nucleus might then become unstable. This idea proved feasible, thus making it possible for elements to be made radioactive by an artificial process.

Thus, if a neutron is fired into, and is captured by, the nucleus, and the modified nucleus becomes unstable, the series decay is similar to the natural radioactive series decay. The nucleus fires out either an alpha or a beta particle or a gamma ray, or a particle and a ray, until a new stable level of some other element is reached. At last, man has found the means to transmute elements. Although precious metals can be processed from base metals in this manner, the cost makes the practice infeasible.

The method of artifically producing radioactivity, thereby producing new isotopes, is another critical development of knowledge which led to the nuclear bomb. An example is the production of plutonium from an isotope of uranium.

A neutron is added to uranium to produce a decay cycle which would not normally occur and which results in the production of plutonium.

$$
\begin{array}{l}
{}_{0}N^{1} + {}_{92}U^{238} \rightarrow {}_{92}U^{239} \rightarrow {}_{93}Np^{239} \rightarrow {}_{94}Pu^{239} \\
\qquad\qquad\qquad\qquad\quad \searrow {}_{-1}\beta^{0} \qquad \searrow {}_{-1}\beta^{0}
\end{array}
$$

Theory of Relativity

In 1905, Dr. Albert Einstein published his "Special Theory of Relativity." It covers all physical phenomena involving uniform linear motion and is exceedingly complex in its full mathematical presentation. Certain portions, however, are reasonably simple, and they contribute much to our understanding of the nuclear bomb.

Prior to Einstein's theory of relativity, scientists had accepted certain laws of conservation. One such law stated that the total mass of the universe remains constant. In simple language, no matter what man does to modify the state or condition of matter, he can neither create nor destroy it. No process in the universe creates or destroys matter by chemical means. This may be illustrated by a well-known experiment. If a known mass of wood and air is placed in an enclosed space and the wood is burned, the total mass remains the same.

Another conservation law stated that the total amount of energy within the universe remains constant. This meant that no process within the universe creates or destroys energy. An example has already been given: the release of energy when hydrogen and oxygen are exploded. The form of the energy might be changed, as the potential energy in gasoline is converted to kinetic heat energy suitable for powering an airplane, but the total amount of energy before the burning of the fuel equals the amount of energy afterward.

One of the basic concepts of Einstein's "Special Theory of Relativity" is that the two laws of conservation are valid but not independent. According to the theory, the sum total of the mass and energy in the universe remains constant, but it is possible to have energy disappear and produce mass, or to have mass disappear and produce energy. The relation between mass and energy is stated in Einstein's simple equation:

$$E=Mc^2$$

In the formula, E represents energy; M, mass; and c, the velocity of light.

Source of Energy for the Fission Bomb

The early nuclear bombs, which were fission weapons, were examples of the conversion of mass into energy as predicted by Einstein in 1905.

In the physics laboratories energy has been directly converted into mass, and vice versa, in the production and destruction of the "anti-particles." This type of process is constantly occurring naturally throughout the universe. The fission process, whereby the nuclear bomb achieves its energy, results from a rearrangement of particles in nuclei and not from destruction of particles themselves. Scientific measurements have revealed that the neutrons and protons have a

greater mass in the nucleus of a heavy atom than in the nucleus of a medium-weight atom. Thus, the mass of protons and neutrons is less when they are in the atoms of elements around zirconium, tellurium, and cesium than when they are in atoms of platinum, uranium, and heavier elements (Fig. 60). The difference in average mass per particle in the nucleus results from the release of energy in

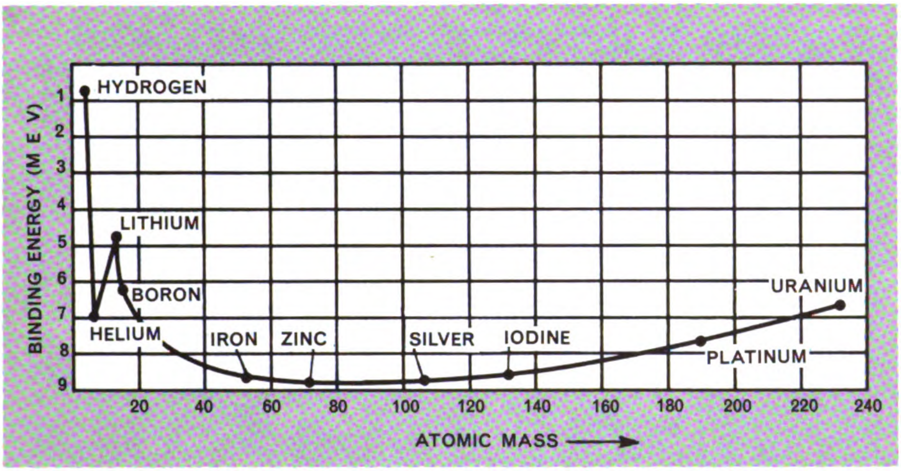


FIGURE 60. The mass of protons and neutrons is less in atoms of elements occurring in the periodic table around iron, zinc, and silver than in atoms of platinum and uranium. This change in mass is measured in mev (million electron volts).

the original formation of the particle; that is, some of the mass of these particles was converted into energy to hold the nucleus together. Protons have positive charges which normally would tend to cause a spontaneous flying apart of the nucleus. Nuclei do not fly apart because of a short-range nuclear force which is not completely understood by physicists at this time. This nuclear force, which is physically manifested by the loss of mass, is referred to specifically as "binding energy." In the measurement of nuclei, it has been empirically proved that for any particular nucleus, the more binding energy released the more stable the nucleus, the end effect being a less than average mass per particle in the nucleus. This explains why the mass of protons and neutrons in iron, zinc, and nickel atoms is less than the mass of protons and neutrons within atoms on either side of these elements on the periodic table. There is a great difference between the weights of free neutrons and protons and an equal number bound together in a nucleus.

If a nucleus of an atom of uranium splits into two parts (the fission process), producing atoms near zirconium, tellurium, or cesium, the difference in the mass of the particles will appear as energy in accordance with Einstein's equation, $E=Mc^2$. Since the uranium isotope is reasonably stable, additional excitation is necessary to cause fissioning. This is accomplished by a neutron

and results in the release of energy in the fission bomb as shown in Figure 61 and in the following equation.

$$\text{Neutron} + {}_{92}U^{235} \rightarrow \begin{cases} \nearrow \text{Fission fragment} \\ \text{Energy} + \text{additional neutrons} \\ \searrow \text{Fission fragment} \end{cases}$$

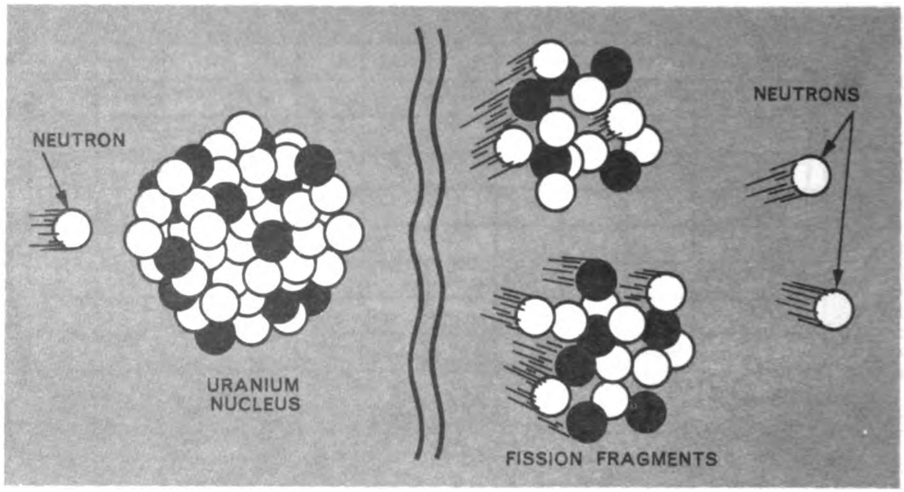


FIGURE 61. Uranium fission illustrates splitting of a U-235 nucleus by a neutron, with formation of fission products and additional neutrons.

The fission fragments produced have atomic numbers that fall around the middle of the periodic table. Energy has been released as the result of the conversion of mass, and the neutrons that have been freed can be put to work to continue the nuclear reaction.

In the use of plutonium in a fission bomb, the following equation applies:

$$\text{Neutrons} + {}_{94}Pu^{239} \rightarrow \begin{cases} \nearrow \text{Fission fragments} \\ \text{Energy} + \text{additional neutrons} \\ \searrow \text{Fission fragments} \end{cases}$$

The energy released from a plutonium fission reaction is a little more than that released from a uranium fission reaction; also, the number of neutrons available to produce further reactions is greater in plutonium fission than in uranium fission. Plutonium is therefore a more energetic nuclear fuel than uranium.

The fission process is the breaking of a nucleus into two parts, with an accompanying release of energy. Although only a small amount of energy is released by the fission of one atom, the fissioning of a large number of atoms may release a vast amount of energy. Notice that fission reactions give off neutrons, which were also necessary to start the reaction. This gives us the possibility

of producing a chain reaction, in which each atom that fissions will induce the fissioning of more atoms (Fig. 62).

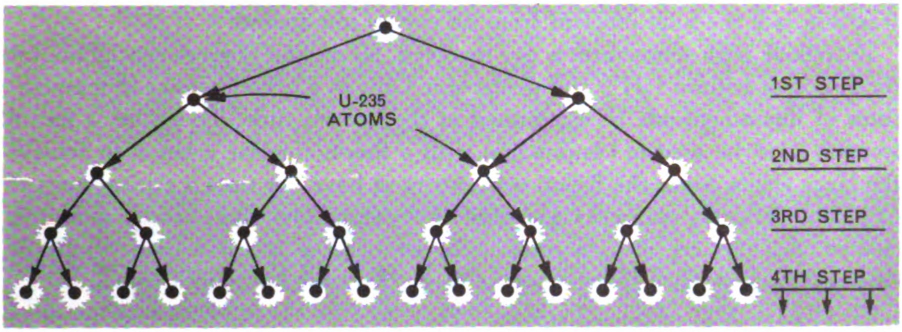


FIGURE 62. Steps in the fissioning of U–235.

The fissionable material in the nuclear bomb must be such that it will not sustain a chain reaction before detonation. During the time that the bomb is inactive, any neutrons present or those produced from a few atoms fissioning must travel out of the mass of the fissionable material without interacting with the plutonium or uranium to produce more neutrons. At the time of detonation, the fissionable material in the bomb is rearranged so as to start and sustain a chain reaction.

The quantity of fissionable material that will sustain a chain reaction is defined as a "critical mass." In the fission bomb, the aim is to produce a maximum release of energy in a minimum amount of time. This is accomplished by producing a supercritical mass within a fraction of a second.

Fusion—Source of Large-Yield Weapons

Energy is also available from combining free particles—protons and neutrons—to form any nucleus. Although no present process can be followed to combine free protons or neutrons to release vast amounts of energy, the combining of isotopes of the lightest element, hydrogen (Fig. 57), can be accomplished to release energy. This process is called nuclear fusion.

The reactions which can produce fusion are as follows:

$${}_1H^2 + {}_1H^3 \rightarrow {}_2He^4 + {}_0N^1 + \text{Energy}$$

$${}_1H^2 + {}_1H^2 \nearrow {}_1H^1 + {}_1H^3 + \text{Energy} \quad \text{(50 per cent of the reactions)}$$

$${}_1H^2 + {}_1H^2 \searrow {}_2He^3 + {}_0N^1 + \text{Energy} \quad \text{(50 per cent of the reactions)}$$

These reactions will not take place as easily as the fission process because of the coulombic repulsive forces of the nuclei. The neutron, being uncharged, easily enters a uranium or plutonium nucleus, while the positively charged nuclei repel each other. To overcome the repulsive force, an increase in temperature can excite the atom to sufficient energy to fuse. A tremendous release of energy

accompanies the fusion process. On a weight comparison basis, a greater release of energy is possible from deuterium ($_1H^2$) fusion than from uranium or plutonium fission. Thus the temperature-induced reactions, or thermonuclear reactions, are the most efficient from an energy standpoint.

Extremely high temperatures are involved, 50 million degrees centigrade for the fusion of tritium ($_1H^3$) and deuterium. Only in a fission bomb can temperatures of this magnitude be established at the present time. Therefore, a fission weapon must be used in conjunction with a thermonuclear weapon to achieve the large yields. Since the fission weapons must have less than a critical mass of fissionable material prior to assembly and detonation, their size is definitely limited. But the size of a thermonuclear warhead or bomb is limited only by deliverability, which then becomes the primary consideration in design.

Yield of Energy

Fission and fusion are two methods for extracting some of the latent energy from the nucleus of the atom. Neither process represents total conversion of a mass to energy. Rather, both produce "leftover" energy from processes which involve splitting a heavy element into two lighter ones (fission), or the combination of light element atoms into atoms of a heavier element.

Total conversion of an element would produce much greater energy than fission or fusion. For example, if a mass one-fifth the size of a nickel (approximately 5 grams) could be converted into energy in 1 hour, the energy equivalent of 30 million horsepower would be released. Yields from atomic fission or fusion could also be expressed in units of horsepower; however, for practical purposes within the context of this chapter, yields are stated in terms associated with fission and fusion bombs.

The power of a nuclear weapon is expressed in terms of its total energy release, or yield, compared with the energy liberated by a TNT explosion. Thus, a 1-kiloton (KT) nuclear bomb is one which produces the same amount of energy as the explosion of 1 kiloton (1,000 tons) of TNT. Similarly, a 1-megaton weapon would have the energy equivalent of 1 million tons (1,000 kilotons) of TNT. The early nuclear bombs, of the type which were dropped over Japan in 1945 and used in the Bikini tests in 1946, released about the same amount of energy as 20,000 tons (20 kilotons) of TNT. Since that time, much more powerful weapons, with energy yields in the megaton range, have been developed.

When it is considered that the fission of 1 pound of uranium or plutonium will release the energy equivalent of 9,000 tons of TNT, it is evident that, in a 20-kiloton nuclear bomb, 2.2 pounds of material undergo fission. However, the actual weight of uranium or plutonium in such a bomb is greater than this amount, because only a part of the nuclear material fissions. The efficiency is thus said to be less than 100 percent.

In the explosion of a high-explosive weapon, nearly all the energy released appears immediately as kinetic (heat) energy, almost the whole of which is converted into blast and shock. In a fission weapon, however, the situation

is different. About 85 percent of the energy released in fission is in the form of kinetic energy, and only a part of this produces blast and shock. The other part of this 85 percent appears as thermal radiation—heat and light rays—which is a result of the extremely high temperatures attained in a nuclear explosion. The fraction of the fission energy emitted as thermal radiation varies with the nature of the weapon and with the conditions of the explosions (about one-third for a fairly high airburst). In general, about 50 percent of the total energy produces blast and shock (Fig. 63).

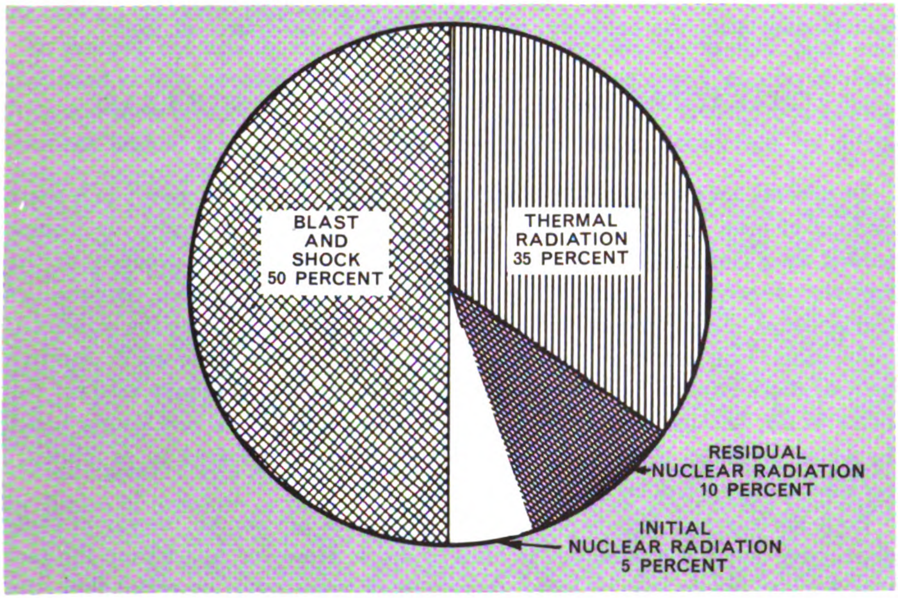


FIGURE 63. Distribution of energy in a typical air burst.

The remaining 15 percent of the energy of the nuclear explosion is released as various nuclear radiations. Of this energy, 5 percent is in the form of initial nuclear radiations produced within a minute or so of the explosion, and the final 10 percent is emitted over a period of time in the form of residual nuclear radiation. This is caused by the radioactivity of the fission products present in the bomb residue after the explosion. It should be noted that there are no nuclear radiations in a conventional explosion, since the atomic nuclei are unaffected.

The initial nuclear radiations consist mainly of gamma rays (resembling X-rays) and neutrons. Both of these, especially the gamma rays, can travel great distances through the air and can even penetrate considerable thicknesses of material. Since these radiations can be neither seen nor felt by human beings, but can have harmful effects even at a distance from their source, they are a very important aspect of a nuclear explosion.

In the course of their radioactive decay, the fission products emit gamma

rays and beta particles (electrons). The subatomic beta particles carry a negative electric charge and move at high speed. Although much less penetrating than gamma rays, beta particles represent a potential hazard.

The spontaneous emission of beta particles and gamma rays from radioactive substances, such as the fission products, is a gradual process, taking place over a period of time and at a rate depending upon the nature and the amount of the material present. Because of the continuous decay, the quantity of radioactive material and the rate of emission of radiation decrease steadily. This means that the residual nuclear radiation of the fission products is most intense soon after the explosion but diminishes in the course of time.

CHARACTERISTICS AND EFFECTS OF NUCLEAR EXPLOSIONS

In general, an explosion is the release of a large amount of energy in a short interval of time within a limited space. The liberation of this energy is accompanied by a considerable increase of temperature, so that the products of the explosion become extremely hot gases. These gases, at very high temperature and pressure, move outward rapidly. In doing so, they push away the surrounding medium—air, water, or earth—with great force, thus causing the destructive blast or shock effects of the explosion. The term "blast" is generally used for the effect in air, because it resembles, and is accompanied by, a very strong wind. In water or under the ground, however, the effect is referred to as "shock," because it is like a sudden impact.

Both nuclear and high-explosive (HE) weapons are similar insofar as their destructive action is due mainly to blast or shock. However, apart from the fact that nuclear bombs can be many thousands of times more powerful than the largest high-explosive bombs, there are other more basic differences. First, a fairly large proportion of the energy in a nuclear explosion is emitted in the form of thermal radiation. This is capable of causing skin burns and of starting fires at considerable distances. Second, the explosion is accompanied by highly penetrating and harmful gamma rays and neutrons which make up initial nuclear radiation. Finally, the substances remaining after a nuclear explosion are sources of residual nuclear radiation for an extended period of time.

Because of these fundamental differences between explosions of nuclear and high-explosive weapons, as well as the tremendous difference in power, the effects of nuclear weapons require special consideration. In this connection, an understanding of the mechanical and radiation phenomena associated with a nuclear explosion is of vital importance.

The phenomena described here accompany the explosion of a 1-megaton (TNT equivalent) nuclear bomb in the air or near the surface of the ground. However, the expected results of explosions of other energy yields will be indicated.

Although this discussion will be concerned primarily with an airburst at a

considerable height above the surface, the modifications resulting from a surface burst will be included.

Configurations and Types of Nuclear Explosions

Nuclear explosions assume characteristic visual configurations, particularly if the bursts occur in air or on the surface. The two most common configurations are the fireball and the atomic cloud, the latter often in mushroom shape. Meteorological conditions—temperature, humidity, wind, precipitation, and atmospheric pressure—may influence some of the observable effects, although the over all characteristics remain unchanged.

In general, the atomic cloud follows, and results from, the fireball. Both are important chiefly because of heat and radiological phenomena associated with them and their time of occurrence in the explosion. Heat, for example, radiating from the fireball is a formidable destructive force, while fallout falls, or drifts laterally, from the atomic cloud.

These configurations are modified by the type of nuclear explosion—whether it is an air, surface, or subsurface burst. The type of explosion also has much influence on magnitude of airblast or ground shock.

The immediate phenomena associated with a nuclear explosion, as well as the effects of blast and thermal and nuclear radiations, vary with the location of the point of burst in relation to the surface of the earth. The main types, as defined below, are airburst, subsurface (underwater and underground) burst, and surface burst.

THE FIREBALL AND ATOMIC CLOUD AS VISUAL PHENOMENA.—We know that the fission of uranium or plutonium in a nuclear weapon leads to the liberation of tremendous energy in a very short time within a limited quantity of matter. As a result, the fission products, the bomb casing and other weapon parts, and the surrounding air are raised to temperatures that approach those in the center of the sun. Because of the intense heat produced by the nuclear explosion, all the materials of the weapon are converted into a gaseous form. At the instant of explosion, these gases are restricted to the region occupied by the original constituents in the bomb, thereby producing pressures which are expressed in millions of pounds per square inch.

Within a few millionths of a second after detonation, intensely hot gases at extremely high pressure appear as a roughly spherical, highly luminous mass—the fireball. The fireball will be dealt with at greater length in the section devoted to heat phenomena.

While the fireball is still luminous, the temperature, in the interior at least, is so high that all the bomb materials are vaporized. This includes the radioactive fission products, uranium (or plutonium) that has escaped fission, and the casing and other materials of the bomb. As the fireball expands and cools, the vapors condense to form a cloud containing solid particles of the bomb debris, as well as many small drops of water condensed from the air sucked into the ascending fireball.

The color of the radioactive cloud is initially red or reddish brown, due to

the presence of various colored compounds, such as nitrous acid and oxides of nitrogen, at the surface of the fireball. These result from the chemical interaction of nitrogen, oxygen, and water vapor in the air at the existing high temperatures. As the fireball cools and condensation occurs, the color of the cloud changes to white, indicating, as in an ordinary atmospheric cloud, the presence of water droplets.

Varying with the height of burst and with the nature of the terrain below, a strong updraft with inflowing winds is produced. Following the initial phase of the explosion, these afterwinds suck up dirt and debris from the earth's surface into the atomic cloud.

At first the rising mass of bomb residue carries the particles upward, but after a time they begin to fall slowly, under the influence of gravity, at rates depending upon their size. Thus a lengthening and widening column of cloud, or smoke, is produced. This cloud consists chiefly of very small particles of radioactive fission products and bomb residues, water droplets, and larger particles of dirt and debris carried up by the afterwinds.

The speed with which the top of the radioactive cloud continues to climb depends on meteorological conditions as well as on the energy yield of the bomb. In general, the cloud will reach a height of 3 miles in 30 seconds and 4.5 miles in about 1 minute, averaging roughly 260 miles per hour during the first minute or so. The rate of rise is indicated for the following heights:

	Time (minutes)	*Rate of rise (mph)*
2 miles	0.3	300
4 miles	.75	200
6 miles	1.4	140
10 miles	3.8	90
14 miles	6.3	35

The eventual height reached by the radioactive cloud depends upon the heat energy of the bomb and upon the temperature gradient and density of the surrounding air. In general, the greater the amount of heat liberated, the greater will be the upward thrust due to buoyancy—or the higher the cloud will ascend. It is probable, however, that the maximum height attainable by a radioactive cloud is affected by the height of the troposphere (the base of the stratosphere).

As a rule, temperature of atmosphere decreases with increasing altitude. However, in some circumstances, an "inversion layer" occurs, where temperature begins to increase with altitude. If the radioactive cloud should reach such a temperature inversion layer, it will tend to spread out to some extent. Nevertheless due to buoyancy of the hot air mass, most of the cloud will usually pass through an inversion layer.

Upon reaching a level where the density of the cloud is the same as that of the surrounding air, or upon reaching the base of the stratosphere, a part of the cloud slows its rise and spreads out horizontally in the characteristic mushroom shape. The altitude of the base of the mushroom head, which is attained within about 8 to 10 minutes, is generally from 5 to 10 miles. The top of the cloud rises

still higher, the altitude increasing with the energy yield of the explosion. For example, in the Pacific tests during 1952–54, devices having energies in the megaton range produced clouds that rose to about 25 miles. A mushroom cloud generally remains visible for about an hour before being dispersed by winds into the surrounding atmosphere and merged with other clouds.

AIRBURST.—An airburst is one in which the bomb is exploded in the air at such a height above land or water that the fireball, at maximum brilliance, does not touch the surface of the earth. For example, in the explosion of a 1-megaton bomb, the fireball may grow until it is nearly 5,800 feet (1.1 mile) across, at maximum brilliance. This means that in the airburst of such a bomb, the point of explosion is at least 2,900 feet above the surface of earth.

The quantitative aspects of an airburst depend upon the actual height of the explosion, as well as upon its energy yield, but the general phenomena are much the same in all cases. Nearly all the shock energy appears as airblast, although if the explosion occurs close enough to the surface, there will also be some ground shock. The thermal radiation travels great distances through the air and is of sufficient intensity to cause semi-severe burns to exposed skin as far away as 12 miles from a 1-megaton bomb explosion in moderately clear weather. The warmth may be felt at a distance of 75 miles. For airbursts of higher energy yields, the corresponding distances will, of course, be greater. Since the thermal radiation is largely stopped by ordinary opaque materials, buildings and clothing can provide protection.

The initial nuclear radiations from an airburst penetrate great distances, but with fairly rapidly decreasing intensity. Like X-rays the nuclear radiations are not easily absorbed, and fairly thick layers of materials, preferably of high density, are needed to reduce their intensity to harmless proportions. For example, at a distance of 1 mile from the airburst of a 1-megaton bomb, a person would probably need the protection of about 1 foot of steel or 4 feet of concrete to be relatively safe from the effects of the initial nuclear radiations.

In the event of a high or moderately high airburst, products of nuclear reaction will be widely dispersed. The residual nuclear radiations arising from these products will be of minor consequence on the ground. On the other hand, if any portion of the fireball touches the ground, radioactive products may fuse with particles of earth, much of which will fall to the ground at points close to the explosion. This dirt and other debris will be contaminated with radioactive material and may represent a possible danger to living organisms.

SUBSURFACE BURST.—In a subsurface burst, the center of the explosion occurs beneath the surface of the ground or water. Since some of the effects of these two types of explosions are similar, they are considered together here.

Most of the shock energy of a subsurface explosion appears as underground or underwater shock, but a certain portion, which decreases with the depth of the burst, escapes and produces airblast. Much of the thermal radiation and initial nuclear radiation will be absorbed within a short distance of the explosion. The energy of the absorbed radiation will merely contribute to the heating of the ground or body of water. Some of the thermal and nuclear radiation

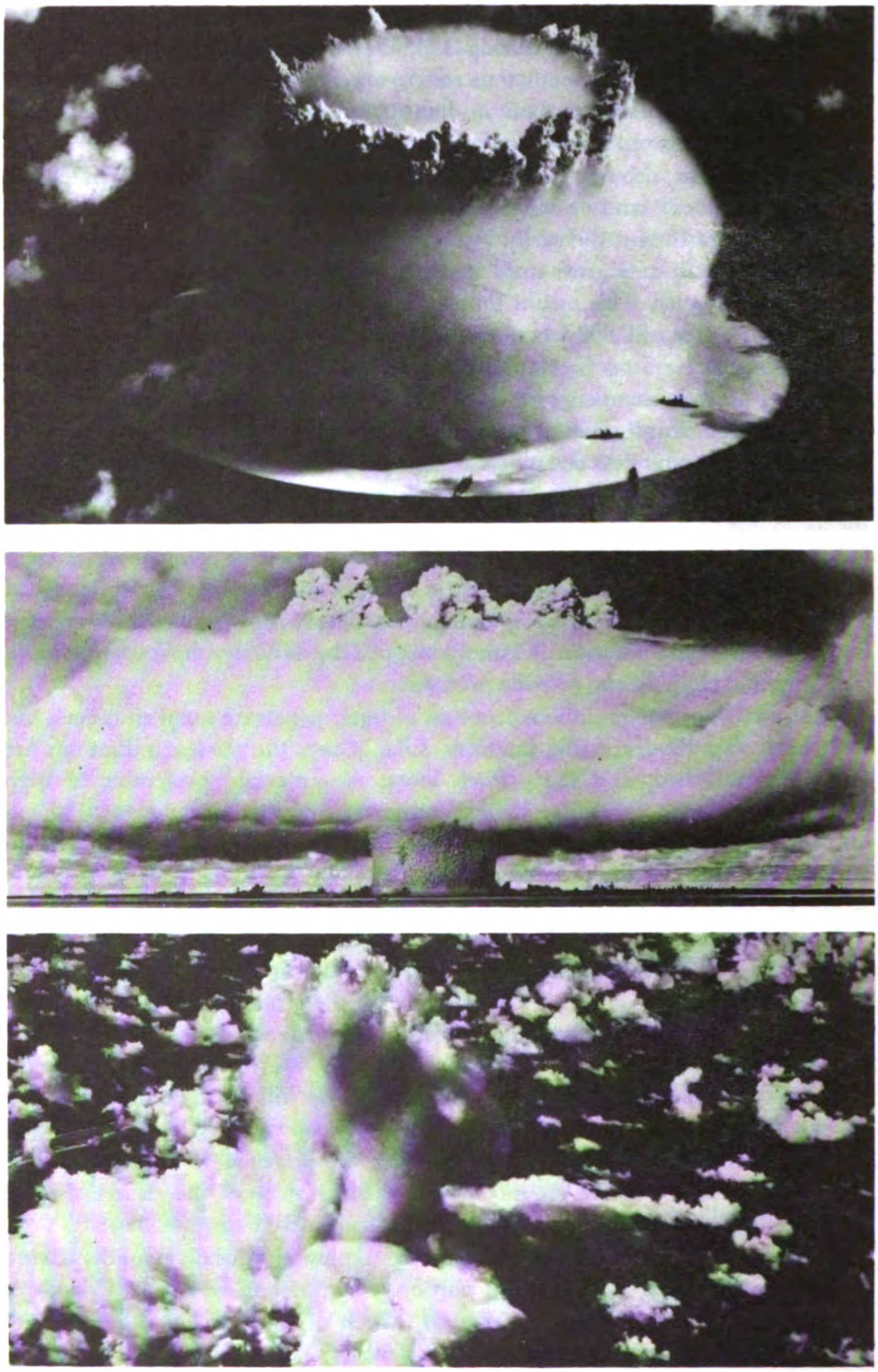


FIGURE 64. Sequence of the nuclear subsurface burst at Bikini Atoll.

will escape, depending upon the depth of the explosion, but the intensities will be less than for an airburst. However, the residual nuclear radiation is particularly significant, since large quantities of earth or water in the vicinity of the explosion will be contaminated with radioactive products.

SURFACE BURST.—A surface burst is considered to be one which occurs at the actual surface of land or water or at any height that permits the fireball, at maximum brilliance, to touch land or water. The energy of the explosion will then cause both airblast and ground or water shock in varying proportions, depending upon the height of the point of burst. Height of burst also determines the amounts of thermal radiation and initial nuclear radiation that can escape from the ball of fire. Residual nuclear radiation can also be a major hazard because of the large quantities of contaminated dust or water that result from the nuclear explosion.

Although the types of burst have been considered as being fairly distinct, there is actually no clear-cut differentiation. As the height of the explosion is decreased, an air burst becomes a surface burst. Similarly, a surface burst merges into a subsurface explosion at a shallow depth, when part of the fireball actually breaks through the surface of the land or water. It is a matter of convenience, however, to consider nuclear explosions by type.

Heat Phenomena

One of the important differences between a nuclear and a conventional (TNT) bomb is that a large proportion of the energy released in a nuclear explosion is in the form of thermal, or heat, radiation. Because of the tremendous amount liberated per unit mass in a nuclear bomb, temperatures up to several million degrees are produced, as compared with a few thousand degrees in a TNT explosion. As a consequence of the high temperature in the fireball, approaching that in the center of the sun, a considerable portion of the released energy appears as thermal radiation.

Within a few milliseconds after the detonation of a nuclear weapon, intensely hot gases, at tremendously high pressures, rapidly form the highly luminous mass known as the fireball. At about seven-tenths of a millisecond, the fireball from a 1-megaton nuclear weapon would appear to an observer 60 miles away to be more than 30 times as bright as the sun at noon. Although the size of the fireball will vary with the bomb energy, luminosity does not vary greatly. However, the larger the yield of the weapon, the longer will be the period of luminosity.

Immediately after the fireball forms, it begins to expand. This expansion is accompanied by a decrease in temperature and pressure, hence a decrease in luminosity. At the same time, the fireball rises like a hot-air balloon. Within seven-tenths of a millisecond from the detonation, the fireball from a 1-megaton bomb expands to a radius of about 220 feet, reaching a maximum radius of about 3,600 feet in 10 seconds. Then measuring some 7,200 feet across, it rises at the rate of 250 to 350 feet per second. After 1 minute, it has cooled to such

an extent that it is no longer visible. It has then risen roughly 4.5 miles above the point of burst.

The nuclear explosion has often been compared to the conventional high explosive detonation in that, except for the yield and nuclear radiation involved, they can be considered similar. When referring to thermal effects, this can be a poor comparison because of the very large proportion of energy released as thermal radiation by a typical nuclear explosion. As was illustrated in Figure 63, over one-third of the energy of a typical nuclear explosion manifests itself in the form of thermal radiation. As soon as the fireball is formed, it begins emitting thermal radiation. Because of the very high temperatures, this radiation consists of ultraviolet (short wavelength), as well as visible and infrared (long wavelength) rays. The maximum temperature attained in a fission bomb is probably several million degrees, as compared with a maximum of 5,000° centigrade (9,000° F.) in a high-explosive bomb.

Thermal radiation travels with the speed of light, so that the time elapsing between its emission from the ball of fire and its arrival at a target a few miles away is quite insignificant.

Due to certain phenomena associated with the absorption of thermal radiation by the air in front of the expanding fireball, the surface temperature undergoes a curious change. While the interior temperature of the fireball falls steadily, the surface temperature decreases more rapidly for a small fraction of a second, then it increases again for a somewhat longer time, after which it falls continuously. In other words, there are two surface temperature pulses: the first is of very short duration, the second lasts for a much longer time. This behavior is generally typical, although the duration of the pulses increases with the energy yield of the explosion.

Corresponding to the two temperature pulses, two pulses of thermal radiation are emitted from the fireball (Fig. 65). In the first pulse, which lasts about one-tenth second for 1-megaton explosion, the temperatures are extremely high.

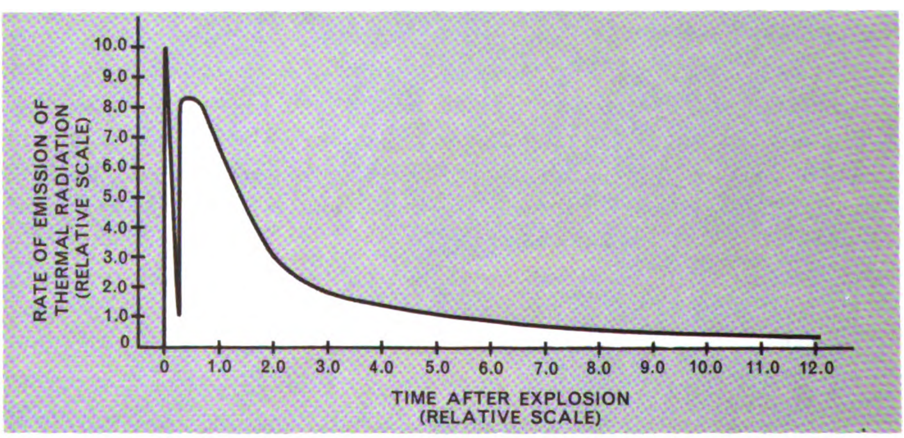


FIGURE 65. Emission of thermal radiation in two pulses.

As a result, much of the radiation emitted in this pulse is in the ultraviolet region. Moderately large doses of ultraviolet radiation can cause painful blisters, and even small doses will redden the skin. However, in most circumstances, the first pulse of thermal radiation would not be expected to produce serious skin burns, for several reasons. First, only about 1 percent of the thermal radiation is emitted in the initial pulse because of its short duration. Second, the ultraviolet rays are so readily attenuated by the intervening air that, at a distance from the explosion, the dose may be comparatively small. Further, it appears that the ultraviolet radiation from the first pulse could cause significant effects on the human skin only within ranges at which other radiation effects are much more serious.

With regard to the second pulse the situation is quite different. This pulse, which may last for several seconds, carries about 99 percent of the total thermal radiation energy from the bomb. Since the temperatures are lower than in the first pulse, most of the rays reaching the earth consist of visible and infrared (invisible) light. It is this radiation which produces most of the skin burns suffered by exposed persons up to 12 miles or more from the explosion of a 1-megaton bomb. For bombs of higher energy, the effective damage range is greater. The radiation from the second pulse can also start fires under certain conditions.

The large amount of thermal radiation characteristic of the nuclear explosion has important consequences. For although most of the destruction from a nuclear airburst is the result of blast—thermal radiation will make a significant contribution to the overall damage through the ignition of combustible materials.

TABLE III*

Effects	*Approximate cal/cm² required*		
	1 KT	100 KT	10 MT
Second-degree bare skin burn	4	5	9
Newspaper ignition	3	5	9
White pine charring	10	18	32
Army khaki summer uniform destruction	18	31	56
Navy white uniform destruction	34	60	109

*Thermal energies are expressed in calories per unit area—i.e., per square centimeter. Note that the amount of energy required for burning, charring, etc., varies inversely with the yield of the nuclear weapon. This is because of the rate at which the energy is delivered. For a given total amount of thermal energy received by each unit area of exposed material, the damage will be greater if the energy is delivered rapidly than if it is delivered slowly. This means that in order to produce the same thermal effect in a given material, the total amount of thermal energy (per unit area) received must be larger for a nuclear explosion of high yield than for one of lower yield, because the energy is delivered over a longer period of time, i.e., more slowly, in the former case.

Additionally, thermal radiation is capable of causing skin burns on exposed personnel at distances where the effects of blast and initial nuclear radiation are insignificant. This difference between the injury ranges of thermal radiation and the other effects mentioned becomes more marked with increasing nuclear weapon yield.

The most important physical effects of the high temperatures resulting from the absorption of thermal radiation are: burning of the skin and scorching, charring, and possible ignition of combustible organic substances such as wood, fabrics, and paper.

Thin or porous materials, such as lightweight fabrics, newspaper, dried grass, and dried rotted wood, may flame when exposed to sufficient thermal radiation.

Table III supplies a comparison of approximate thermal energies required to produce a variety of physical effects.

Thick organic materials, such as plastics, heavy fabrics, and wood more than one-half inch thick, char but do not burn. Dense smoke, even jets of flame, may

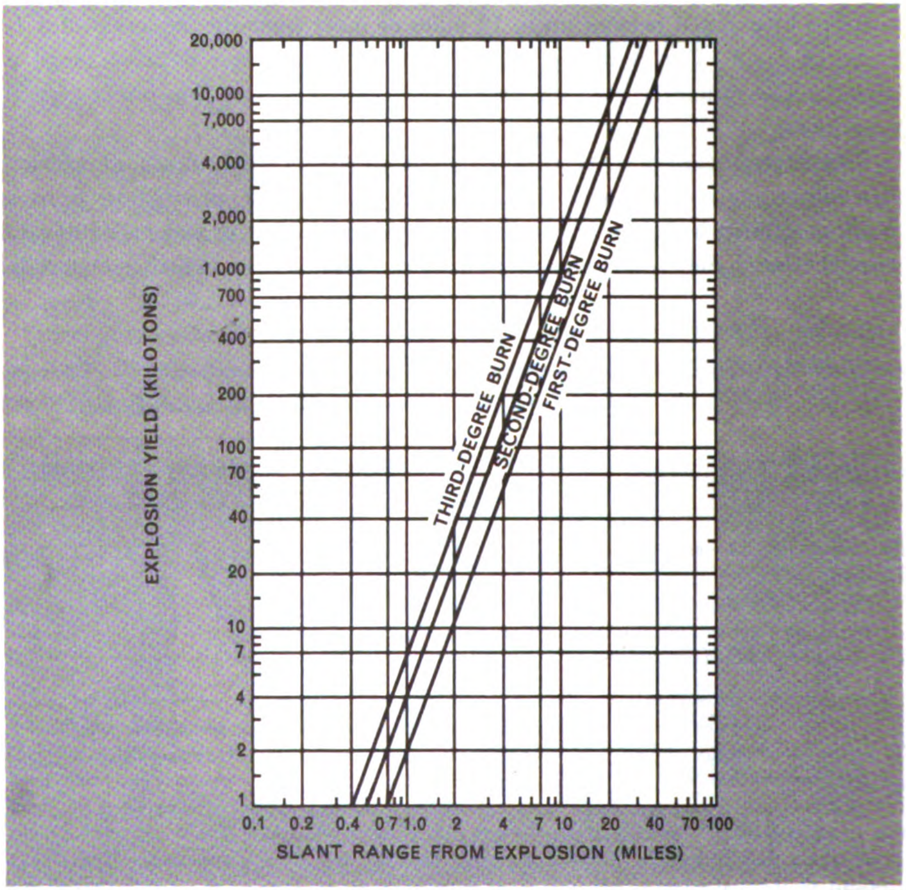


FIGURE 66. Distances at which burns occur on bare skin.

be emitted, but the material does not sustain ignition. Thin combustible material would probably burst into flame at the same location.

But perhaps the most serious consequence of thermal radiation is its ability to produce serious burn injury to personnel at long ranges. Figure 66 is included to show the ranges at which moderate first-, second-, and third-degree burns can occur from nuclear explosions. The graph is computed assuming a typical air burst with clear atmospheric conditions prevailing. For a typical surface burst, the distances would need to be scaled down to about 60 percent of those stated.

Reading the graph, it can be seen that personnel exposed to a typical air burst (1 MT explosion) at 9 miles might be expected to receive moderate second-degree burns.

Conventionally, burns are classified according to their severity, in terms of degree (or depth) of injury. In first-degree burns there is only redness of the skin. A moderate sunburn is an example of a first-degree burn. Healing should occur without special treatment and there will be no scar formation.

Second-degree burns are deeper, more severe, and are characterized by the formation of blisters. A severe sunburn is an example of a second-degree burn.

In third-degree burns, the full thickness of the skin is destroyed. Unless skin grafting techniques are employed, there will be scar formation at the site of the injury.

The extent of the area of skin which has been burned is also important. Thus, a first-degree burn over the entire body may be more severe than a third-degree burn to one spot. The larger the area burned, the more likely is the appearance of symptoms involving the whole body. Further, there are certain critical, local regions, such as the hands, where almost any degree of burn will partially incapacitate the individual.

Thermal radiation can be the cause of flash burns or flame burns. Flash burns are directly caused by the radiant energy of the fireball. Flame burns are distinguished from flash burns in that they are caused by fire, no matter what the origin. Flame burns occur as a secondary result of thermal radiation, for example, those resulting from the fires started by thermal radiation.

A highly significant effect of the nuclear explosion is the very large number of flash burns. This was one of the most striking facts about the nuclear bombing of Japan in World War II. It has been estimated that 20 to 30 percent of the fatalities at Hiroshima and Nagasaki were due to flash burns, as distinct from flame burns. Although significant, it should be realized that these illustrated results were magnified due to the fact that the atmosphere was very clear and that the summer clothing worn was light and scanty.

Another danger of a nuclear explosion is its possible effect on the eyes. Thermal radiation can cause both retinal burns and flash blindness.

Because of the focusing action of the lens of the eye, enough energy can be collected to produce a burn on the retina at such distance from a nuclear explosion that the thermal radiation intensity is too small to produce a skin burn. As a result of accidental exposures during nuclear tests, a few retinal burns have been experienced at a distance of 10 miles from the explosion of a 20-KT

weapon. It is believed that under suitable conditions, such burns might have resulted at even greater distance. Retinal burns occur so soon after the explosion that reflex actions, such as blinking and contraction of the eye pupil, give only limited protection. In all instances, there will be at least a temporary loss of visual acuity, but the ultimate effect will depend on the severity of the burn and on its location on the retina.

Because of the more or less remote chance that an individual will be looking directly at the ball of fire, the chance of temporary "flash blindness" or "dazzle," due to the flooding of eye with brilliant light is much more prevalent than retinal burns. Flash blindness is of a temporary nature and vision is regained within a comparatively short time. However, flash blindness is of military significance, since it may extend to 2 or 3 hours.

When thermal radiation falls upon any material or object, part may be reflected, part will be absorbed, and the remainder, if any, will pass through and ultimately fall upon other material. It is the amount of radiation absorbed by a particular material that produces heat and so determines the damage suffered by that material. Highly reflective and transparent substances do not absorb much of the thermal radiation and so are relatively resistant to its effects. A thin material will often transmit a large proportion of the radiation falling upon it, and thus escape serious damage. A dark fabric will absorb a much larger proportion of thermal radiation than will the same kind of fabric when it is white. However, a light-colored material which blackens (or chars) readily in the early stages of exposure to thermal radiation will behave essentially as a dark material regardless of its original color.

Thermal radiation travels in straight lines like ordinary light. For this reason any solid, opaque material, such as a bulwark, gun shield, hill, or tree, between a given object and the fireball will act as a shield and thus provide protection from direct thermal radiation.

Atmospheric conditions also play a part in the amount of thermal radiation received by a particular object. However, they do not play as important a part in attenuating thermal radiation as was once suspected. When visibility is in excess of 2 miles (light haze or clearer), the total amount of thermal radiation received will be essentially the same as that on an "exceptionally clear" day (visibility more than 30 miles). This is because any decrease in direct radiation is largely compensated for by an increase in scattered radiation.

When visibility is less than 2 miles because of rain, fog, or dense industrial smoke, there will be a definite decrease in radiant energy received at any specified distance.

Clouds can also affect the amount of radiant energy received. For example, if an explosion occurs above a cloud layer, there will be considerable attenuation at ground level. Conversely, should an explosion occur beneath a cloud layer, some of the radiation which would normally have been lost to space will be scattered back to earth.

Artificial white (chemical) smoke can be used to attenuate thermal radiation, for it acts like fog in this respect. A dense smoke screen between the point of burst

and a given target can reduce thermal radiation to as little as one-tenth of the amount which would otherwise have been received at the target.

Characteristics of the Blast Wave

At a fraction of a second after the explosion, a high-pressure wave develops and moves outward from the fireball. This is the blast wave, which causes much of the destruction accompanying an airburst. The front of the blast wave—the shock front—travels rapidly away from the fireball, behaving like a moving wall of highly compressed air. After the lapse of 10 seconds, when the fireball of a 1-megaton nuclear bomb has attained its maximum expansion (7,200 feet across), the shock front is some 3 miles further ahead. At 50 seconds after the explosion, when the fireball is no longer visible, the blast wave has traveled about 12 miles. It is then moving at about 1,150 feet per second, which is slightly faster than the speed of sound at sea level.

Most of the material damage caused by the airburst of a nuclear weapon is due mainly to the blast or shock wave that accompanies the explosion. Most structures will suffer some damage from airblast when the overpressure (pressure in excess of ambient atmospheric pressure) is about one-half pound per square inch or more. The distance to which this overpressure level will extend depends primarily on the magnitude of the explosion and on the height of the burst.

A difference in the air pressure acting on separate surfaces of a structure produces a force on the structure. This force is an important factor in the destructive effect of a blast wave and will be treated in succeeding sections. The maximum pressure existing at the shock front is called the peak overpressure. Other characteristics of the blast wave, such as dynamic pressure, duration, and time of arrival, will also be discussed.

The principal characteristic of a blast wave is that the pressure is highest at the moving front and falls off toward the interior region of the explosion. As the blast wave travels in the air away from its source, the overpressure at the front steadily decreases, and the pressure behind the front steadily falls off. After a short time, when the shock front has moved away from the fireball, the pressure behind the front drops below that of the surrounding atmosphere, and the negative phase of the blast wave forms. In this phase the air pressure is below that of the original, or ambient, atmosphere.

During the negative overpressure (rarefaction, or suction) phase, a partial vacuum is produced and the air is sucked in, instead of being pushed away, as in the case in the positive (compression) phase. In the positive phase, the wind associated with the blast wave blows away from the explosion; but in the negative phase, the direction is reversed. At the end of the negative phase, the pressure has essentially returned to ambient. The peak negative values of the overpressure are small in comparison with the peak positive overpressures.

Variation of Blast Overpressure With Time.—At a fixed location the overpressure in the blast wave changes with time. The variation of overpressure with time, observable for a few seconds following the detonation, is shown in

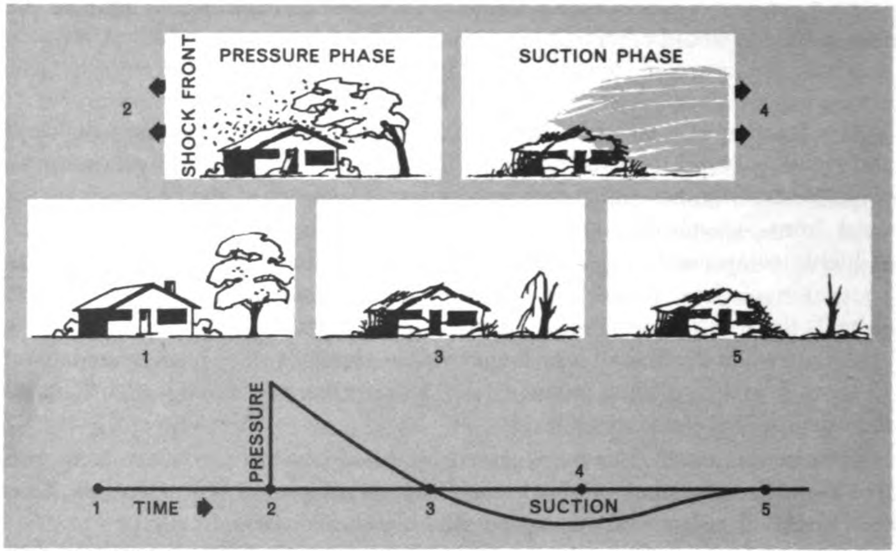


FIGURE 67. Variation of pressure with time at a fixed location and effect of the blast wave passing over a structure.

Figure 67. The corresponding general effects to be expected on a light structure, a tree, and a small animal are indicated at the left of the figure.

After the detonation there is no increase in pressure at a given location for the brief interval during which the blast wave is traveling to that point from the point of the explosion. When the shock front arrives, the pressure suddenly increases to the peak overpressure. In Figure 67, point 1 represents the time of the explosion. At the arrival of the shock front (point 2), a strong wind begins to blow away from the explosion. This is often referred to as a "transient" wind because its velocity decreases fairly rapidly.

Following the arrival of the shock front, the pressure falls rapidly (point 3) to that of the original, or ambient, atmosphere. Although the overpressure is now zero, the wind continues in the same direction for a short time. The interval from point 2 to point 3 (roughly one-half to 1 second for a 20-kiloton explosion and 2 to 4 seconds for a 1-megaton explosion) represents the passage of the positive, or compression, phase of the blast wave. It is during this interval that most of the destructive action of the airburst will be experienced.

The pressure in the blast wave continues to fall until it is below that of the surrounding atmosphere. In the time interval from points 3 to 5, which may be several seconds, the negative, or suction, phase of the blast wave passes the given location. For most of this period, the transient wind blows toward the explosion. Any destruction during the negative phase is usually minor, since the maximum negative overpressure is always considerably smaller than the peak overpressure at the shock front. As the negative phase passes, the pressure falls at first and then rises toward that of the ambient atmosphere, which is reached at the time

represented by point 5. The blast wind has then effectively ceased and the direct destructive action of the air blast is over. There may still, however, be indirect destructive effects caused by fire.

DYNAMIC PRESSURE.—Although the destructive effects of the blast wave have usually been related to values of the peak overpressure, an equally important quantity is the dynamic pressure—air pressure which results from the wind behind the shock front of the blast wave. For many types of buildings the degree of blast damage depends largely on the drag force associated with the strong transient winds which accompany the blast wave. The drag force is influenced by the shape and size of the structure, but generally depends upon the peak value of the dynamic pressure and its duration at a given location.

The dynamic pressure is related to the wind velocity and the density of the air behind the shock front. Both of these quantities may also be related to the overpressure under certain conditions at the shock front. For very strong shocks, the dynamic pressure is larger than the overpressure, but if the overpressure is below 69 pounds per square inch at sea level, the dynamic pressure is smaller. Like the peak shock overpressure, the peak dynamic pressure falls with increasing distance from the explosion center, but at a different rate. The corresponding values of peak overpressure, peak dynamic pressure, and maximum blast wind velocities (measured at increasing distances from ground zero) are indicated in Table IV. Dynamic pressure is seen to decrease more rapidly with distance than does the shock overpressure.

TABLE IV.—*Overpressure, Dynamic Pressure, and Wind Velocity in Air at Sea Level*

Peak overpressure (psi)	*Peak dynamic pressure* (psi)	*Maximum wind velocity* (mph)
72	80	1,170
50	40	940
30	16	670
20	8	470
10	2	290
5	0. 7	160
2	0. 1	70

At a given location, the dynamic pressure changes with time in a manner somewhat similar to the change in the overpressure, but the pressure behind the shock front decreases at a different rate. Figure 68 indicates qualitatively how the two pressures vary in the course of the first second or so following arrival of the shock front. Both pressures increase sharply when the shock front reaches the given point, and subsequently they decrease. The curves show the overpressure and the dynamic pressure falling to zero at the same time. Actually, the wind velocity and the dynamic pressure do not drop to zero until slightly later, chiefly because of the inertia of the moving air, but for purposes of estimating damage the difference is not significant.

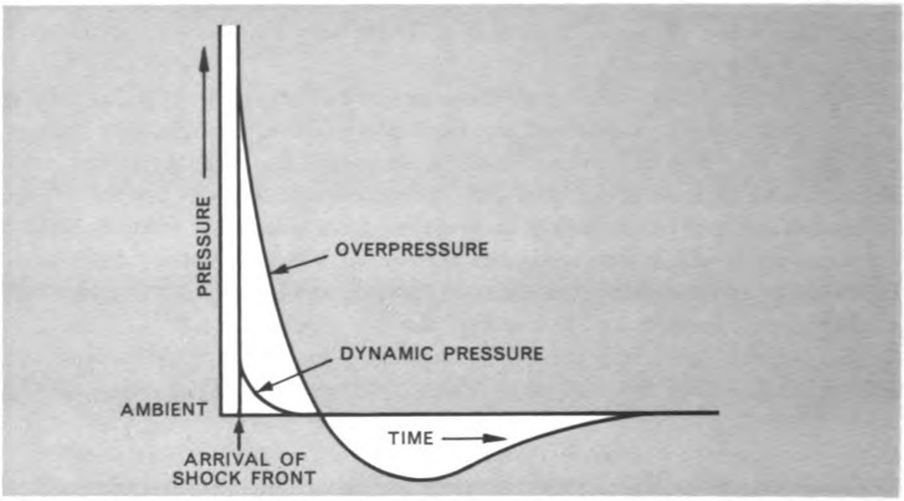


FIGURE 68. Variation of overpressure and dynamic pressure with time at a fixed location.

During the negative phase of the blast wave, the dynamic pressure (drag force) is very small and acts in the opposite direction, therefore causing only negligible damage.

ARRIVAL TIME AND DURATION.—As pointed out, a finite time interval is required for the blast wave to move out from the explosion center to any particular location. This time interval, or arrival time, depends upon the energy yield of the explosion and the distance involved; thus, at 1 mile from a 1-megaton burst, the arrival time would be about 4 seconds. Initially, the velocity of the shock front is many times the speed of sound, but it decreases as the blast wave moves outward. Finally, at long ranges, the blast wave becomes essentially a sound wave, and its velocity approaches ambient sound velocity.

The duration of the blast wave at a particular location also depends on the energy of the explosion and the distance from the point of burst. The duration of the positive phase is shortest at close ranges and increases as the blast wave moves outward. At one mile from a 1-megaton explosion, for example, the duration of the positive phase of the blast wave is about 2 seconds.

As noted earlier, the transient wind velocity behind the shock front falls to zero, and then reverses itself after the positive overpressure phase has ended. Consequently, the duration of dynamic pressure may exceed the duration of overpressure to an extent which varies with the pressure level involved. However, only insignificant dynamic pressures remain after the overpressure positive phase. Therefore, the interval during which the dynamic pressure is effective may be considered as essentially the duration of the positive overpressure phase (Fig 68).

SURFACE REFLECTION.—When the incident blast wave from an airburst strikes a denser medium, such as land or water surfaces, it is reflected. The for-

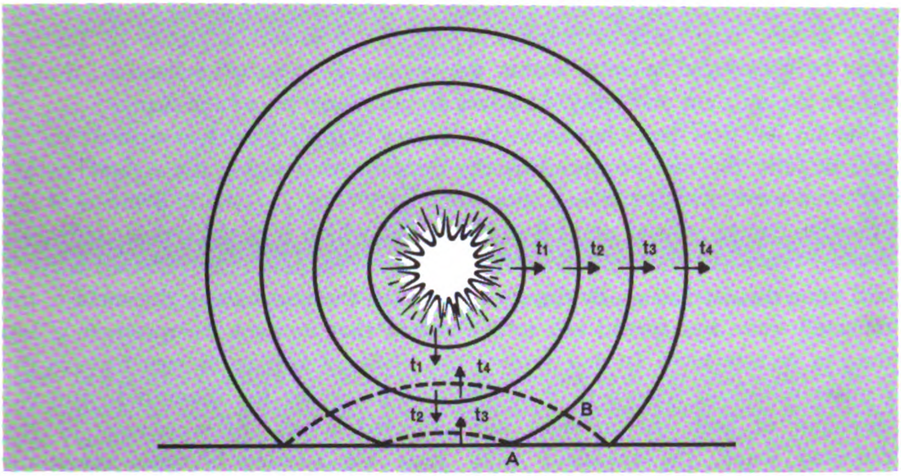


FIGURE 69. Reflection of the blast wave at the surface in an air burst (t_2 and t_4 indicate successive times).

mation of the reflected shock wave is represented in Figure 69, which shows four stages in the outward motion of the spherical blast originating from an airburst. In the first and second stages, the shock front has not reached the ground; in the third stage, the wave has been reflected, as indicated by the dotted line.

When such reflection occurs, a person or object on the surface will experience a single shock, since the reflected wave is formed instantaneously. Consequently, the value of the overpressure thus experienced at the surface is generally considered to be entirely a reflected pressure. In the region near ground zero, the total reflected overpressure is more than twice the value of the peak overpressure of the incident blast wave. The exact value of the reflected pressure will depend on the strength of the incident wave and the angle at which it strikes the surface.

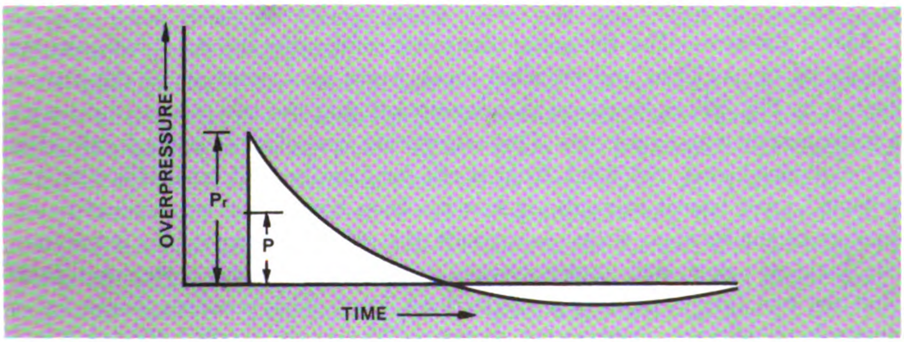


FIGURE 70. Variation of overpressure with time at a point on the surface in the region of regular reflection (P indicates incident overpressure; P_r, the overpressure after reflection).

The variation in overpressure with time, as observed at a point on the surface near ground zero (such as point A in Fig. 69), is shown in Figure 70. Point A may be considered as lying within the region of "regular" reflection; that is, where the incident and reflected waves do not merge above the surface.

At any location somewhat above the surface in this region, two separate shocks will be felt: the first produced by the incident blast wave; the second, by the reflected wave, which arrives a short time later (Fig. 71). An illustration of this situation can be seen at point B in Figure 69, which is in the regular reflection region. When the incident shock front reaches this point, the reflected wave is still some distance away. By the time it reaches the point above the surface, the reflected wave has spread out to the extent that its peak overpressure is less than at surface level. In determining the effects of airblast on structures in the regular reflection region, it is necessary to allow for the magnitude and the direction of both the incident and reflected waves. After passage of the reflected wave, the transient wind near the surface becomes essentially horizontal.

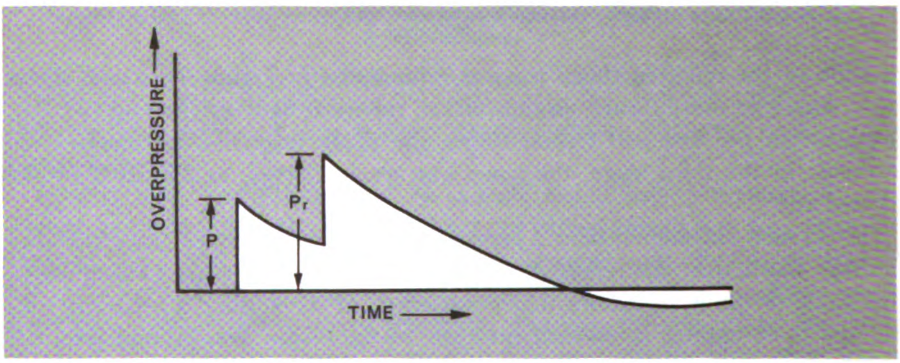


FIGURE 71. Variation of overpressure with time at a point above the surface in the region of regular reflection (P indicates incident overpressure; P_r, total overpressure after reflection).

MACH EFFECT.—The foregoing discussion concerning the delay between the arrival of the incident and reflected shock fronts at a point above the surface (see **B** in Fig. 69) is based on the assumption that the two waves travel with approximately equal velocities. This assumption is applicable immediately after the explosion, when the shock front is not far from ground zero. However, the reflected wave travels through air that has been heated and compressed by the passage of the incident wave. As a result, the reflected wave moves faster than the incident wave and, under certain conditions, eventually overtakes it so that the two fuse to produce a single shock front. This process of wave interaction is called mach, or irregular, reflection. The region in which the two waves have merged is therefore called the mach, or irregular, region in contrast to the regular region where they have not merged.

The fusion of the incident and reflected shock fronts is indicated schemat-

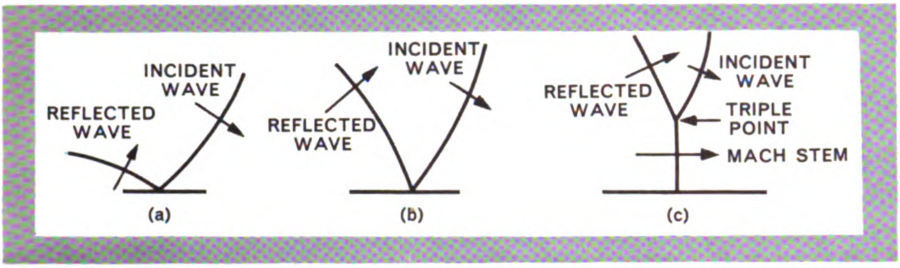


FIGURE 72. Fusion of the incident and reflected waves and formation of the mach stem.

ically in Figure 72, which shows a portion of the profile of the blast wave close to the surface. At left, *a* represents the situation at a point fairly close to ground zero (see A in Fig. 69). At a later stage and farther from ground zero (see *b*, Fig. 72), the steeper front of the reflected wave shows that it is traveling faster than, and is consequently overtaking, the incident wave. Finally, the reflected shock wave near the ground overtakes, and fuses with, the incident shock wave to form a single shock front—the mach stem (*c*). The point at which the incident shock wave, reflected shock wave, and mach fronts meet is called the triple point.

As the reflected wave continues to overtake the incident wave, the triple point rises and the height of the mach stem increases. Any object located either at or above the ground, within the mach region, and below the triple point path, will experience a single shock. The behavior of this fused or mach shock is the same as that previously described for shock fronts in general. The overpressure at a particular location will fall off with time and the positive (compression) phase will be followed by a negative (suction) phase, as shown in Figure 67.

At points in the air above the triple point path, for example, an aircraft or the top of a high building, two shocks will be felt. The first is produced by the incident blast wave; the second, a short time later, by the reflected wave. When a bomb is detonated at the surface (a contact surface burst), only a single merged wave develops. Consequently, only one shock will be experienced either on or above the ground.

As concerns the destructive action of the airblast, at least two important aspects of the reflection process should be considered. One is that only a single shock is experienced in the mach region below the triple point as compared with the separate incident and reflected waves in the region of regular reflecting. The other is that, since the mach stem is nearly vertical, the accompanying blast wave is traveling in a horizontal direction at the surface, and the transient winds are approximately parallel to the ground (Fig. 72). Thus, in the mach region, the blast forces on above-ground structures and other objects are directed nearly horizontally, so that vertical surfaces are loaded more intensely than horizontal surfaces.

The distance from ground zero at which mach fusion and the formation of the mach stem begin depends upon the magnitude of the detonation and the height

of the burst. For a typical airburst of 1-megaton energy yield, the mach stem beings to form about 1.3 miles from ground zero. As the burst point is lowered, this distance is reduced; or if the detonation occurs at a greater height, mach fusion begins farther away. If the airburst takes place above a certain height, regular reflection will occur and no mach stem will be formed.

HEIGHT OF BURST AND BLAST DAMAGE.—The height of burst and the magnitude of the nuclear explosion are important factors in determining the extent of damage at the surface. These two factors generally determine the variation of pressure with distance from ground zero and other associated blast wave characteristics, such as the distance from ground zero at which the mach stem begins to form. As the height of burst for an explosion of given energy yield is decreased, certain consequences can be expected: mach reflection begins nearer to ground zero, and the overpressure at the surface near ground zero is increased. An actual contact surface burst leads to the highest possible overpressures near ground zero. Other observable phenomena are cratering and ground shock, which will be described later.

Because of the relationships between the yield and the height of burst required to produce certain blast effects, a weapon of very large yield detonated at a height of several thousand feet will still produce blast wave phenomena which resemble those of a near-surface burst. On the other hand, explosions of weapons of smaller energy yields at these same heights will have the characteristics of typical high airbursts.

In the nuclear explosions over Japan during World War II, the height of burst was about 1,850 feet. It was estimated, and has since been confirmed by nuclear tests, that a 20-kiloton explosion at this height would cause maximum blast damage to structures on the ground for the particular targets concerned. Actually, there is no single optimum height of burst, with regard to blast effects, for any specified explosion energy yield, because the nature of the target will dictate the most effective height of burst. As a rule, strong (hard) targets will require low air or surface bursts. For weaker targets, which are destroyed or damaged at relatively low overpressures or dynamic pressures, the height of burst may be raised in order to increase the area of damage, since the mach effect extends the distances at which low pressures result.

Contact Surface Burst

With the lowering of the height of burst to a contact surface burst, there is gradual modification in airblast effects. When a considerable part of the fireball touches the ground, an important new blast effect is observed—the cratering effect.

AIRBLAST.—The general airblast phenomena resulting from a contact surface burst are somewhat different from those of an airburst. In a surface explosion, the front of the blast wave in the air is hemispherical in form (Fig. 73). There is no region of regular reflection, and all objects and structures on the surface, even close to ground zero, are subjected to airblast similar to that in the mach region below the triple point for an airburst. The shock front is therefore

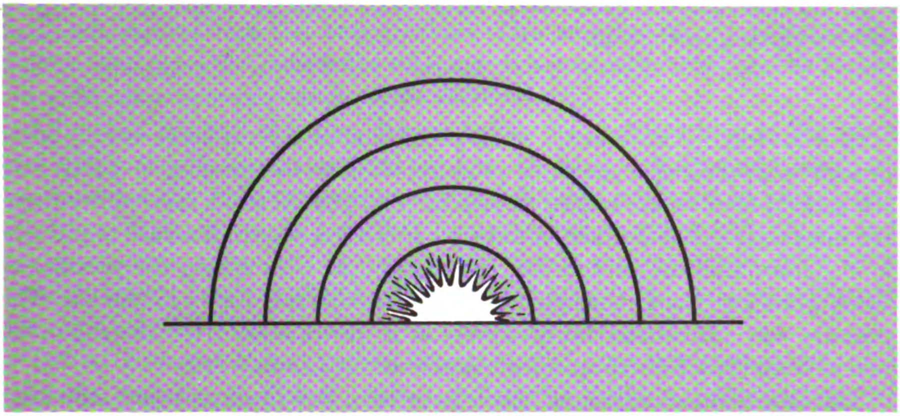


FIGURE 73. Blast wave from a contact surface burst; the incident and reflected waves coincide.

assumed to be vertical for most structures near the ground, with both overpressure and dynamic pressure decreasing at different rates behind the shock front. The transient winds behind the shock front near the surface are essentially horizontal.

CRATERING.—The considerable quantity of material that is vaporized by the extremely high temperatures is sucked upward by air currents accompanying the rising fireball. Eventually all condenses in the atomic cloud. The formation of a crater results principally from the displacement of soil and other material by pressures produced as the hot gas bubble rapidly expands. As a result of the explosion, this material is pushed, thrown, and scoured out. Because the gases move outward, very little of the earth falls back into the crater, although a considerable amount is deposited around the edges to form the upper layers of a lip.

It has been estimated that if only 5 percent of the energy of a 1-megaton bomb is used for cratering, something like 20,000 tons of vaporized soil material will be added to the normal constituents of the fireball. Also, the high winds at the earth's surface will cause large amounts of dirt, dust, and other particles to be sucked up as the fireball rises.

The vaporization of dirt and other material which occurs when the fireball touches the earth's surface, and the removal of material by the blast wave and winds accompanying the explosion, together result in the formation of a crater. The size of the crater will vary with the height of burst, with the character of the soil, and with the energy of the bomb. It is believed that a 1-megaton bomb will produce no appreciable crater unless detonation occurs at an altitude of 450 feet or less.

If a nuclear weapon is exploded near the surface of the water, large amounts of water will be vaporized and carried up into the radioactive cloud. For example, supposing that 5 percent of the energy of the 1-megaton bomb is expended in this manner, about 100,000 tons of water will be converted into vapor. At

high altitudes this will condense to form water droplets, similar to those in an ordinary atmospheric cloud.

Ground Shock

In a nuclear surface burst a small proportion of the explosive energy is expended in producing a shock, or pressure, wave in the ground, of which only the general features are known at present. This ground shock wave differs from the blast wave of the airburst in having a much less sudden increase of pressure at the front and also in decaying less sharply. At close range, the pressure or shock gradient is large enough to destroy the cohesive forces in the soil. The pressure wave attenuates fairly rapidly as it moves away from the explosion, and at considerable distances resembles acoustic or seismic waves.

The effects of underground shock have been described as being somewhat similar to those of an earthquake of moderate intensity, although there are also significant differences. In comparison with airblast, the pressure in the ground shock waves falls off more rapidly with distance, and consequently the radius of damage from ground shock, or "earthquake effect," is small.

The shock waves in the ground are complex, but their general characteristics can be summarized briefly. At the surface a series of waves move outward like waves in water. These surface waves radiating from the center of the explosion produce what is called ground roll, which is felt as an oscillation of the surface as the waves pass any given location. In addition, a pulse from the expanding gas bubble forms a semicircular wave front which produces compression and shear waves below the surface of the ground.

The effect of ground shock pressure on an underground structure differs somewhat from that of airblast on a structure above ground. A structure exposed to airblast experiences something like a sudden blow, followed by the drag effect of the blast wind. This type of effect is not associated with underground shock. Because the medium through which a ground shock wave travels is similar in density to that of the underground structure, the responses of the ground and the structure are closely related. That is to say, the movement—acceleration, velocity, and displacement—of the underground structure is largely determined by the motion of the ground itself. This fact has an important influence on the damage criteria associated with both surface and underground explosions.

Radiation

It has been previously pointed out that 15 percent of the total energy yield of a typical nuclear weapon is distributed in the form of nuclear radiations. Let us explore further what this radiation consists of, how it occurs, and what its dangers are.

In any nuclear explosion there is an initial flux of radiations consisting mainly of gamma rays and neutrons. Both of these (especially gamma radiation) travel great distances through the air, and can penetrate great thicknesses of material. Remaining within the fireball are fission products and unfissioned bomb ma-

terial. These fission products and unfissioned bomb material are also radioactive, and emit gamma rays and beta particles. This emission of beta particles and gamma rays from the radioactive substance is a gradual process, and its hazard therefore remains over a significant period of time.

All of the nuclear radiation discussed thus far in this section is the result of fission reactions. No fission products are associated with the fusion reaction; neutrons are the only significant nuclear radiations produced in pure fusion reactions. Thus, it can be seen that for explosions in which both fission and fusion processes occur, the proportions of specific radiations will differ from those of typical fission explosions. However, for present purposes, the difference may be disregarded.

Initial Nuclear Radiation.—The explosion of a nuclear bomb is associated with the emission of various nuclear radiations: neutrons, gamma rays, and alpha and beta particles. Essentially all the neutrons and part of the gamma rays are emitted in the actual fission process; that is, these radiations are produced simultaneously with the nuclear explosion. Some of the neutrons liberated in fission are immediately absorbed (or captured) by various nuclei present in the bomb, and this capture process is usually accompanied by the instantaneous emission of gamma rays. The remainder of the gamma rays and the beta particles are liberated over a period of time as the fission products undergo radioactive decay. The alpha particles are expelled, in an analogous manner, as a result of the decay of the uranium (or plutonium) which has escaped fission in the bomb.

The initial nuclear radiation can be defined as that emitted from both the fireball and the atomic cloud within the first minute after the explosion. It includes neutrons and gamma rays given off almost instantaneously, as well as the gamma rays emitted by the radioactive fission products in the rising cloud. Although alpha and beta particles are present in the initial radiation, they are not considered here because, being so easily absorbed, they will move no more than a few yards from the atomic cloud.

The 1-minute duration of the initial nuclear radiation was originally estimated on the basis of certain characteristics of the 20-kiloton bomb. As a consequence of attenuation in air, the effective range of the gamma rays emitted during fission and during radioactive decay of the fission products is roughly 2 miles. Any emission of gamma rays above that altitude can be ignored, insofar as their effect at the earth's surface is concerned. Therefore, when the atomic cloud has reached a height of 2 miles, the effects of the initial nuclear radiations are no longer significant. Since the cloud rises this distance in above a minute, the initial nuclear radiation is defined as that emitted during the first minute after the explosion.

For a bomb of higher energy, the maximum distance over which the gamma rays are effective will be larger than for a 20-kiloton bomb. But at the same time, there is an increase in the rate at which the cloud rises. Similarly, for a bomb of lower energy the effective distance is less, but the rate of ascent of the cloud is less, also. The period over which the initial nuclear radiation

extends may therefore be considered as the same—1 minute—regardless of the energy release of the bomb.

Neutrons are the only significant nuclear radiations produced directly in the thermonuclear reactions. Although alpha particles (helium nuclei) are also formed, they do not travel very far from the explosion. Some of the neutrons will escape, but others will be captured by the various nuclei present in the exploding bomb. Those neutrons absorbed by fissionable species may lead to the liberation of additional neutrons, as well as to the emission of gamma rays, as described above for an ordinary fission bomb. In addition, the capture of neutrons in thermonuclear reactions is usually accompanied by the emission of gamma rays. Therefore, neutrons and gamma rays largely make up the initial radiation from a bomb in which both fission and fusion (thermonuclear) processes occur. The relative proportions of these two radiations may be somewhat different than for a bomb in which all the energy release is due to fission, but for present purposes the difference may be disregarded.

FALLOUT AND RESIDUAL RADIATION.—As the height of burst of a nuclear explosion occurs nearer the surface of the earth (or sea) larger and larger proportions of the earth (or water) enter the fireball and are fused or vaporized. When sufficient cooling has occurred, the fission products become incorporated with the earth particles as a result of the condensation of the vaporized products into fused particles of earth, etc. As the violent disturbance due to the explosion of the nuclear weapon subsides, these contaminated particles fall gradually back to earth. This effect is referred to as the fallout. The extent and nature of the fallout can range between wide extremes—dependent on the energy yield and design of the bomb, the height of the explosion, the nature of the surface beneath the point of burst, and the meteorological conditions. In the case of an airburst occurring at an appreciable distance above the earth's surface, so that no large amounts of dirt (or water) are sucked into the cloud, the inherent radiation will be widely dispersed. On the other hand, a nuclear explosion occurring at or near the earth's surface can result in severe contamination by the radioactive fallout.

It should be understood that fallout is a gradual phenomenon extending over a period of time. There can be considerable fallout—many hours after the surface detonation of a nuclear weapon, and many miles away. Additionally, there is a worldwide fallout which occurs for years after a nuclear explosion. Fallout that occurs within 24 hours of a nuclear explosion is referred to as local fallout.

Fission products, which make up the greatest hazard in residual radiation, are initially very radioactive. However, this activity falls off at a fairly rapid rate as the result of decay. Figure 74 shows the exponential rate of decay of fission products after a nuclear explosion.

The radiological effects from a typical airburst are completely overshadowed by the effects of blast and thermal radiation. An exception to this would be a "low" airburst of a high yield weapon where there would be extensive induced radioactivity in the vicinity of ground zero. Radiological effects might also be of some consequence to those persons shielded from the primary causes of casualties.

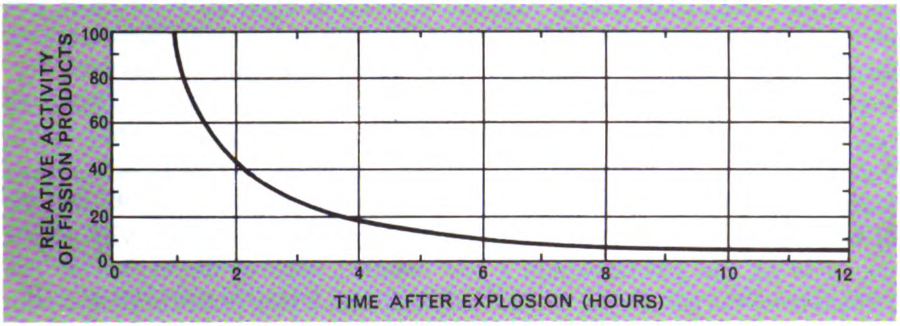


FIGURE 74. Rate of decay of fission products after a nuclear explosion.

A nuclear surface explosion presents an entirely different picture. With a surface burst, even though the induced activity will be considerable, the activity of the fallout will be of so much greater consequence that the former may be neglected in comparison.

A nuclear explosion occurring at or near the earth's surface can result in severe contamination by radioactive fallout. For example, the fallout from the detonation of a powerful thermonuclear device at Bikini Atoll on March 1, 1954, caused substantial contamination over an area of more than 7,000 square miles. The contaminated area was roughly cigar-shaped, extending approximately 20 miles upwind and 220 miles downwind. The width in the crosswind direction was variable, the maximum being close to 40 miles. Actually, both the direction and the velocity of the wind, particularly in the upper atmosphere, have a significant influence on the shape and extent of the contaminated area. The wind characteristics must be considered in predicting the fallout pattern following a nuclear explosion.

The surface burst causes large amounts of earth (water), dust, and debris to be taken up into the fireball in its early stages. Here they are fused or vaporized and become intimately mixed with the fission products and other bomb residues. As a result there is formed, upon cooling, a tremendous number of small particles contaminated to some distance below their surfaces with radioactive matter. In addition, there are considerable quantities of pieces and particles, covering a range of sizes from large lumps to fine dust, to the surfaces of which fission products are more or less firmly attached.

The larger (heavier) pieces, which will include a great deal of contaminated material scoured and thrown out of the crater, will not be carried up into the mushroom cloud, but will descend from the column. Provided the wind is not excessive, these large particles, as they fall, will form a roughly circular pattern around ground zero (although the circle will be somewhat eccentric as the result of any wind). Most of this heavier material referred to above will descend within an hour or so.

The smaller particles present in the atomic cloud will be carried up to a height of several miles, and may spread out some distance in the mushroom cloud

before they begin to descend. The actual time taken to return to the earth, and the horizontal distance traveled, will depend upon the original height attained, the size of the particles, and upon the wind in the upper atmosphere.

The fraction of the total radioactivity of the bomb residues that appears in the fallout depends upon the extent to which the fireball touches the surface. Thus, the proportion of available activity increases as the height of the burst decreases and more of the fireball comes in contact with the earth (or water). In the case of a contact burst, some 50 percent of the total residual radioactivity will be deposited on the ground within a few hundred miles of the explosion. The remainder of the activity will remain suspended for a long period of time as with an airburst.

The pattern of contamination will vary with the wind velocities and directions at all altitudes between the ground and the height of the atomic cloud.

Note that most of the areas downwind will not be seriously contaminated until hours after the explosion. As an example (Fig. 75), a location 32 miles downwind will have a dose rate of about 30 roentgens/hour 1 hour after the detonation. At 6 hours, the dose rate has increased to 1000r/hr. Finally at 18 hours, it is down to roughly 300r/hr. The increase in dose rate from 1 to 6 hours means that fallout was not complete at 1 hour after the explosion. With respect to the accumulated dose received, at 1 hour the stipulated point will not have received

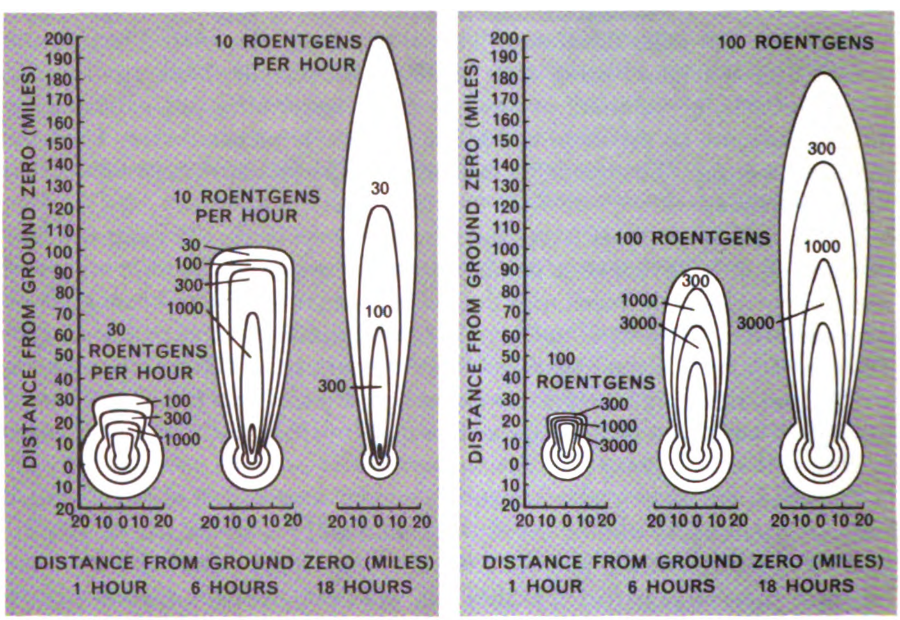


FIGURE 75. Dose-rate contours from fallout at 1, 6, and 18 hours after a surface burst with fission yield in the megaton range (effective wind velocity, 15 miles per hour). Right: Total (accumulated) dose contours from fallout at 1, 6, and 18 hours after surface burst with fission yield in the megaton range (effective wind velocity, 15 miles per hour).

any appreciable radiation because the fallout has only started to arrive; while at the end of 6 hours, the total dose has reached over 3,000 roentgens.

Although the example given above is for the surface burst of a high fission yield nuclear weapon, the fallout phenomena associated with a low fission yield weapon are essentially the same except for differences in degree.

The extent of residual radiation accompanying an underground burst will depend primarily on the depth of burst and the weapon yield. With regards to initial radiation, it is either nonapparent or inconsequential by comparison to the residual radiation.

If the explosion occurs at sufficient depth below the surface, essentially none of the bomb residues and neutron-induced radioactive materials will escape to the atmosphere. There will be no appreciable fallout.

On the other hand, if the burst is near the surface so that the ball of fire actually breaks through, the consequences as regards fallout will not vary greatly from those of a surface burst. Other circumstances being more or less equal, the contamination in the crater area following an underground burst will be about the same as for a surface explosion of equal fission yield. However, the total contaminated area for a shallow underground burst will be greater because of the larger amount of fission products present in the fallout.

Radiological effects of underwater bursts closely parallel those of underground origin. The base surge, consisting of a contaminated cloud or mist of small water droplets, also has a parallel in the underground phenomena. It is interesting to note that experts are placing lesser significance on the base surge as a source of contamination. It is now felt that although the base surge will materially contribute to the overall contamination, rain-out from the atomic cloud is of more consequence.

An important difference between an underwater burst and one occurring under the ground is that the radioactivity remaining in the water is gradually dispersed, whereas that in the ground is not. Therefore, as a result of diffusion of the various bomb residues, mixing with large volumes of water outside the contaminated area, and the natural decay, the radiation intensity of the water in which a nuclear explosion has occurred will decrease fairly rapidly. Additionally, fission products will settle to the bottom of the body of water, thus greatly attenuating the radiological hazards.

The harmful effects of radiation appear to be due to the ionization (and excitation) produced in the cells that make up living tissue. As a result of ionization, some of the constituents that are essential to normal functioning are damaged or destroyed. Some of the products formed may act as cell poisons. Additionally, the living cells are frequently unable to undergo mitosis, so that normal cell replacement is inhibited.

The effects of nuclear radiations on living organisms depend not only on the total dose; that is, on the amount absorbed, but also on the rate of absorption; i.e., on whether it is acute or chronic. In an acute exposure, the whole radiation dose is received in a relatively short period of time. It has somewhat arbitrarily been defined as that dose received during a 24-hour period. Delayed radiations,

TABLE V.—*Expected Effects of Acute Whole-Body Radiation Doses*

Acute dose (roentgens)	*Probable effect*
0 to 50	No obvious effect, except possibly minor blood changes.
80 to 120	Vomiting and nausea for about 1 day in 5 to 10 percent of exposed personnel. Fatigue but no serious disability.
130 to 170	Vomiting and nausea for about 1 day, followed by other symptoms of radiation sickness in about 25 percent of personnel. No deaths anticipated.
180 to 220	Vomiting and nausea for about 1 day, followed by other symptoms of radiation sickness in about 50 percent of personnel. No deaths anticipated.
270 to 330	Vomiting and nausea in nearly all personnel on first day, followed by other symptoms of radiation sickness. About 20 percent deaths within 2 to 6 weeks after exposure; survivors convalescent for about 3 months.
400 to 500	Vomiting and nausea in all personnel on first day, followed by other symptoms of radiation sickness. About 50 percent deaths within 1 month; survivors convalescent for about 6 months.
550 to 750	Vomiting and nausea in all personnel within 4 hours from exposure followed by other symptoms of radiation sickness. Up to 100 percent deaths; the few survivors convalescent for about 6 months.
1000	Vomiting and nausea in all personnel within 1 to 2 hours. Probably no survivors from radiation sickness.
5000	Incapacitation almost immediately. All personnel will be fatalities within 1 week.

like those which may be received from fission products, persist over a longer period of time and this type of exposure is of the chronic type.

The distinction between acute and chronic exposure lies in the fact that, if the dose rate is not too high, the body can achieve partial recovery from some of the consequences of the nuclear radiations while still exposed. In addition to the above, the percentage of body exposure has significance. It follows, then, that whereas a person would most probably die as the result of acute exposure of 700 roentgens whole-body radiation, he would probably suffer no critical effects if the dose were spread over a year—or if it were localized to a hand or foot.

The data provided in Tables V and VI are also plotted in Figure 76. Each shows the effects of acute, whole-body radiation.

It can be noted in both the tables and the illustration that a particular effect is associated with a range of exposure doses. The reason for this uncertainty is that there are many factors, some known and some unknown, which determine

TABLE VI.—*Summary of Clinical Symptoms of Radiation Sickness*

Time after exposure	*Survival improbable (700 r or more)*	*Survival possible (550 r to 300 r)*	*Survival probable (250 r to 100 r)*
1st WEEK	Nausea, vomiting, and diarrhea in first few hours	Nausea, vomiting, and diarrhea in first few hours	Possibly nausea, vomiting, and diarrhea on first day
	No definite symptoms in some cases (latent period)	No definite symptoms (latent period)	No definite symptoms (latent period)
	Diarrhea Hemorrhage Purpura Inflammation of mouth and throat Fever Rapid emaciation Death (mortality probably 100 percent)		
2d WEEK		Epilation (loss of hair) Loss of appetite and general malaise Fever	
3d WEEK		Hemorrhage Purpura Petechiae (small red blotches) Nosebleeds Pallor Inflamation of mouth and throat Diarrhea Emaciation	Epilation Loss of appetite and malaise Sore throat Hemorrhage Purpura Petechiae Pallor Moderate emaciation Diarrhea
4th WEEK		Death in most serious cases (mortality 50 percent for 450 roentgens)	Recovery likely in about 3 months unless complicated by poor previous health or superimposed injuries or infections

the effect on the body of a specified radiation exposure dose. For in addition to the biological variations among individuals, there are such considerations as the ages of exposed personnel and their state of health, depth of penetration into the body and the organs absorbing the radiation, and the orientation of the body with reference to the source of the radiation (possible shielding of one part of the body with another).

A further matter of note is that the sooner the symptoms of radiation sickness appear after exposure, the more serious the consequences will be. There is a

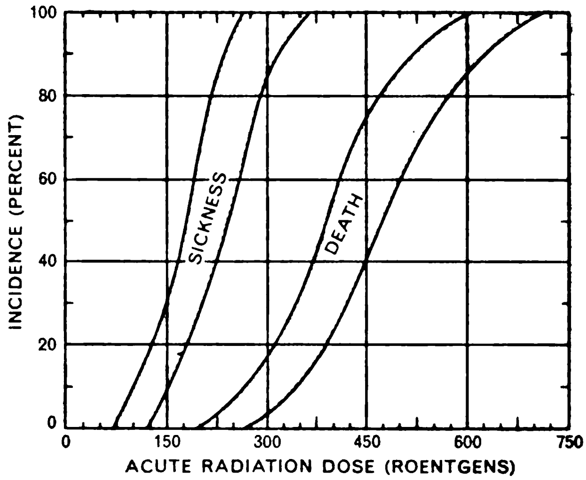


FIGURE 76. Incidence of sickness and death due to acute exposure to various doses of nuclear radiation.

latent period between the first symptoms of radiation exposure and a further condition of sickness.

RADIOLOGICAL WARFARE AS A PART OF CBR

Some distinction was made in the previous chapter between utilization of radiation energy, along with heat and blast, as an integrated weapon—the nuclear bomb—and application of radiation energy as a primary weapon. Radiation used as a primary weapon has been classified as a more unusual application, and has been grouped for this reason with chemical and biological warfare. The term CBR (Chemical, Biological, and Radiological) warfare results from this. The initial radiation of a nuclear weapon is not usually classed as radiological warfare.

In light of the above definition, radiological agents can be classed into two groups: those which may derive from a controlled reactor or accelerator, and are disseminated by means similar to bacteriological warfare and chemical warfare agents, and those which are deliberately created by the explosion of a nuclear device at the combat location. There is no information on any stockpiled radiological agents for use in war, so any description of possibilities must be in general terms.

In theory, it is possible to create particular isotopes in a reactor or in an accelerator which could have uniform characteristics to fit a particular need. In practice, the costs may be too great in all countries to make this worth the trouble. Because of differences in half life of particular isotopes, they may fit either tactical or strategic needs. For example, some isotopes could be so "hot"

as to deny, let us say, a mountain pass to advancing troops, if the dose rate were so high that unacceptable casualties would result. But such a very hot isotope would also probably have a short half life so that after a relatively brief time the area would be once again safe to reenter. On the other hand, other isotopes are long lived. Troops could pass through an area dusted with these and accept the low cost in current casualties and long-run sematic and genetic

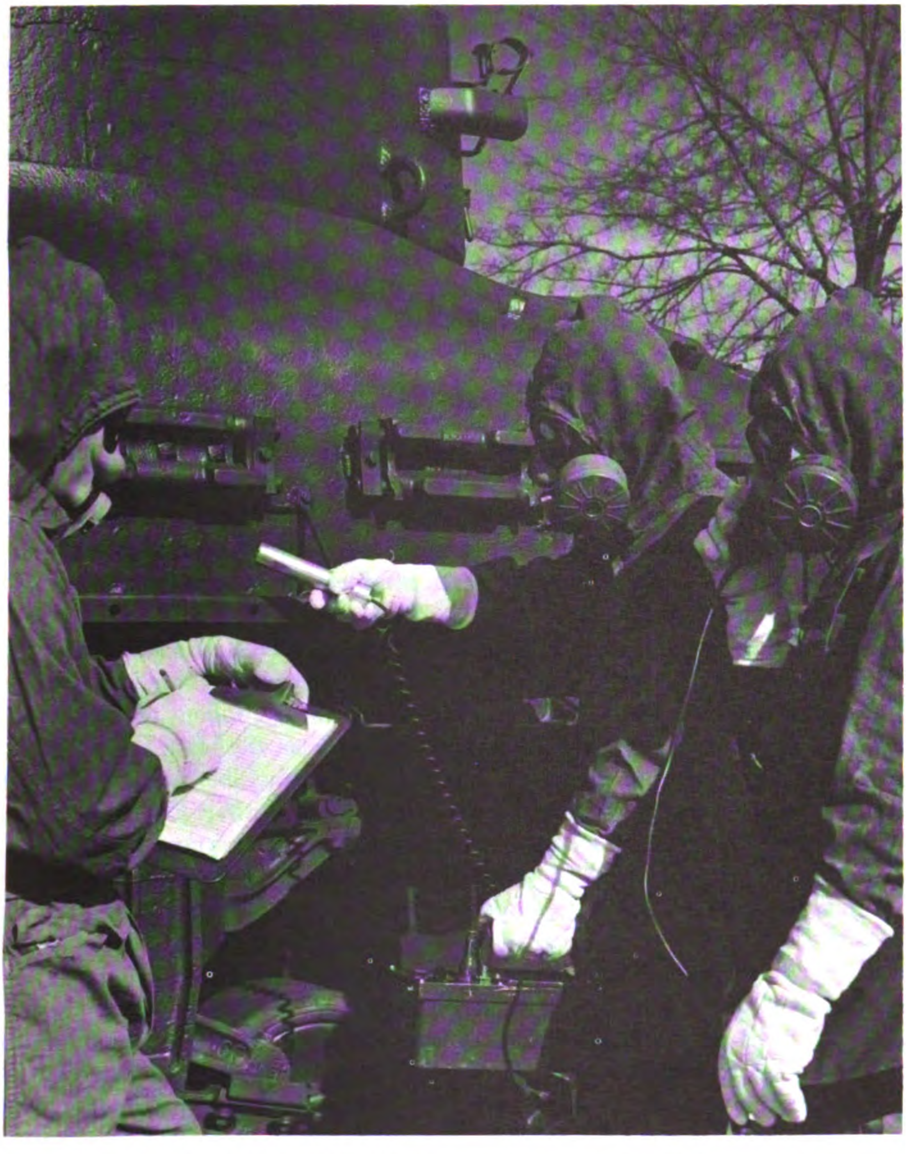


FIGURE 77. A CBR team examines a tank for radioactive contamination. One member of the team takes readings on the Geiger counter, and the other two members record the data and transmit it by radio.

damage which might be very little if only a few hours were spent there. But the area might be quite unsafe for a garrison to stay in, or for a civilian population to live in and to raise crops.

The United States has made an effort to produce nuclear weapons which have a minimum of harmful fallout. These are particularly useful for antiaircraft defense purposes or for picking off specific military targets with a minimum of damage to surrounding areas and populations. But the world is also very much aware that large weapons may be employed in ways which produce acute fallout problems, as shown by the samplings made from Soviet tests. The debris from a bomb and the ground materials which may be sucked up into the cloud from a surface burst provide a mixture of isotopes with many different half lives, some of which create intense radioactivity and then taper off, and others of which cause lingering problems for an appreciable period, even years, conceivably.

Radioisotopes produce the same three types of radiation given off by nuclear explosions—alpha, beta, and gamma rays. By way of review, alpha rays are a stream of particles, the nuclei of helium atoms stripped of electrons. Because they are relatively large, they do not travel far—only 4 inches in air, and they penetrate only a short distance into the outer layers of skin. However, if an alpha source is ingested or inhaled, it can cause severe damage. Beta rays are free electrons, smaller particles. They travel several yards in air and will penetrate the body to the lower skin levels. They do less damage particle for particle entered than do the larger alpha rays. Ingestion or inhalation of beta sources is also dangerous. Gamma rays, true electromagnetic radiation, are an X-ray capable of penetrating matter of considerable thickness, and hence can do considerable damage.

The initial flash of a nuclear weapon and the fireball release a stream of both neutrons and gamma rays, both very penetrating. These effects and the damage they may cause are virtually instantaneous. In contrast, fallout of radioactive isotopes may continue for some hours downwind from the blast, and after the heavier debris has been deposited, may continue in invisible form, as smaller particles come down at distances even hundreds of miles away. Overhead cover, careful scrubbing, and protection of food and water are important to protection. Personnel wearing masks and protective clothing may be able to enter contaminated areas for limited periods of time, depending upon the readings shown on detection instruments which would indicate what dose is to be tolerated in comparison with the urgency of entry into such an area.

If a radioisotope were laid down as a munition apart from a nuclear weapon, standard tables of estimated half lives used for bomb debris would not necessarily be applicable. However, instrument readings with a time lapse would supply the information required to estimate half lives, so that judgments could be made as to whether the risk was one largely of hours or days and weeks.

Public discussion has identified the possibility of encasing a nuclear weapon with cobalt to increase vastly the hazards of fallout. Such an action probably would carry grave perils for the attacking nation as well as the victim when

winds carried the radioactive cloud to many parts of the world. It is conceivable, however, that there are other substances which might be used to modify a nuclear weapon to provide other effects of a radiological nature.

Radiological warfare may or may not be developed in the future deliberately by one of the nuclear powers to include stored radioisotopes as well as by-products of nuclear explosions. It is subject to limitations of difficulties and expense as well as great danger.

▲
Before and during a B–29 precision strike against a major railroad repair yard target in North Korea.
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CHAPTER 8

TARGET INTELLIGENCE

From the experiences with high-explosive bombs in World War II came a vast accumulation of knowledge about targets. This knowledge proved useful during the Korean conflict against tactical objectives, even though it could not be put to full use because of the political considerations that kept United Nations air forces away from most strategic targets. Behind the political considerations loomed the specter of the atomic age, the realities of which had already influenced target study. In the latter days of World War II, Hiroshima and Nagasaki, Japan, had been destroyed; each by a single bomb. Except for testing purposes, no such weapon has been used since, but the fact that they

were once used and can be again points up the impracticability of discussing targets without also considering the weapons to be employed against the targets. New weapons have thus given birth to new target concepts.

Scientific and technological developments since World War II have given the world, among other things, fusion bombs of more awesome destructiveness than the fission bombs dropped on the two Japanese cities, ballistic missiles with nuclear warheads which can span continents in minutes, and a variety of nuclear weapons of assorted yields which permit prediction and control of the amount of destruction for a single detonation. Technology—and necessity—has also shown the world how to disperse and harden its weapon-launching sites, and how to keep other missile-launchers mobile. On the other hand, technology has not yet shown us how to hit a mobile target with a ballistic missile, nor has it yet provided an adequate defense for cities, which are fixed as to their locations, and hence are highly vulnerable as targets. These are some of the developments—and some of the problems—which have caused changes in target study.

This is not to say that target experience gained during World War II and in Korea has become useless. On the contrary, targeting, which has changed and developed to keep pace with new weapons and new concepts, has evolved from the experience with high explosives released from aircraft either above or very near the targets. Let us see to what extent target study has evolved from recent war experience and to what extent it still depends on older techniques and concepts, keeping in mind, of course, that targeting must be an ever-fluid study if it is to keep pace with expanding technological developments. We shall start first with the definition of a target.

The word target may be defined in numerous ways, depending upon the sense in which it is used. A target may be a geographic place. For example, during one phase of a bombing mission, the target would be the place toward which the bombers were flying. In this sense, according to the United States Air Force Dictionary, the target must be reached in order to be hit, as in the phrases "to get through to the target" or "fighter escort to the target and back." In a second definition, as illustrated by a different phase of the bombing mission, a target is a specific thing or place to be hit or aimed at; e.g., a synthetic plant or a communications center. The statement "The bombs were released on the target" would apply to this definition. In other definitions, a target may be a group of objects marked for attack, such as "Shipping became a prime target;" or, as applied to an organization, "The Air Force is a tempting target for enemy sabotage and propaganda." The word target will be used in all of these senses at different times in this chapter.

In common with other areas of military study, the study of targets in warfare has become more complex along with the world's industrial and technological organization. As a consequence, a complete definition of a military target can perhaps no longer be kept simple, but a broad generalization might state that a military target is any person, thing, idea, entity, or location selected for destruction, inactivation, or rendering nonusable with weapons which will reduce or destroy the will or ability of the enemy to resist.

While the above generalization at first glance may seem to be sufficiently all-inclusive to serve as a practical definition, it might not necessarily have a completely valid or practical application. For example, the cost of attacking a target might be too high; also in our time, the destruction or inactivation of any enemy with some ultimate type of weapon might also destroy or have adverse effects upon the side which has launched the weapon, or destroy within the enemy country things it would be undesirable to destroy, such as the capacity to rebuild and to rehabilitate following the war. The full implications of such weapons are still the subject of extensive debate.

Conversely associated with target study is weapon study. As weapons have proliferated and grown amazingly in destructiveness, target considerations have altered accordingly. This situation constitutes a seeming anomaly in target study which requires some explanation. We are about to consider the nature and types of targets, how information about enemy targets is gathered and distributed to users, and what considerations enter into the selection of targets for attack. Much of this information is not applicable or pertinent under most conditions of unlimited warfare. Under such conditions of warfare only the broadest and most basic strategic considerations would dictate the spots at which nuclear weapons would be aimed: for example, the economic and psychosocial targets of greatest vulnerability in any enemy nation. In general, it may be said that the larger the destructive capacity of a nuclear weapon, and the wider their use, the less important pinpoint target selection becomes. With use of nuclear weapons, a near-miss on any conventional scale is immaterial. A very high-yield nuclear weapon's destructive capability is all-inclusive within a radius of many miles: target selectivity within this radius is nonexistent.

Much of the material in this chapter would have little pertinence in a total type of warfare characterized by unlimited use of high-yield nuclear weapons. But even such a total war could, in its later stages, be fought in part and in portions of the world in a theater-type of operation by opposing armed forces using conventional weapons and low-yield nuclear weapons with air support. In such an operation, target selection in the conventional manner described below would be practical. The present chapter subject is also pertinent for study because of another type of warfare which has evolved since the advent of nuclear weapons—limited war. High-explosive wars of the Korean War type may be fought again.

COMPONENTS OF A NATIONAL STRUCTURE AS TARGETS

Targets within a nation fall into four categories: military, economic, political, and psychosocial (Fig. 78). In target study, the elements of power grouped within these four categories are structural components of national strength. As targets, such components must be analyzed to determine which should be destroyed in order to cause the entire instrument or organization they make up to malfunction or break down completely. The destruction of certain of the components could render the whole useless to the enemy, and could, in fact, under-

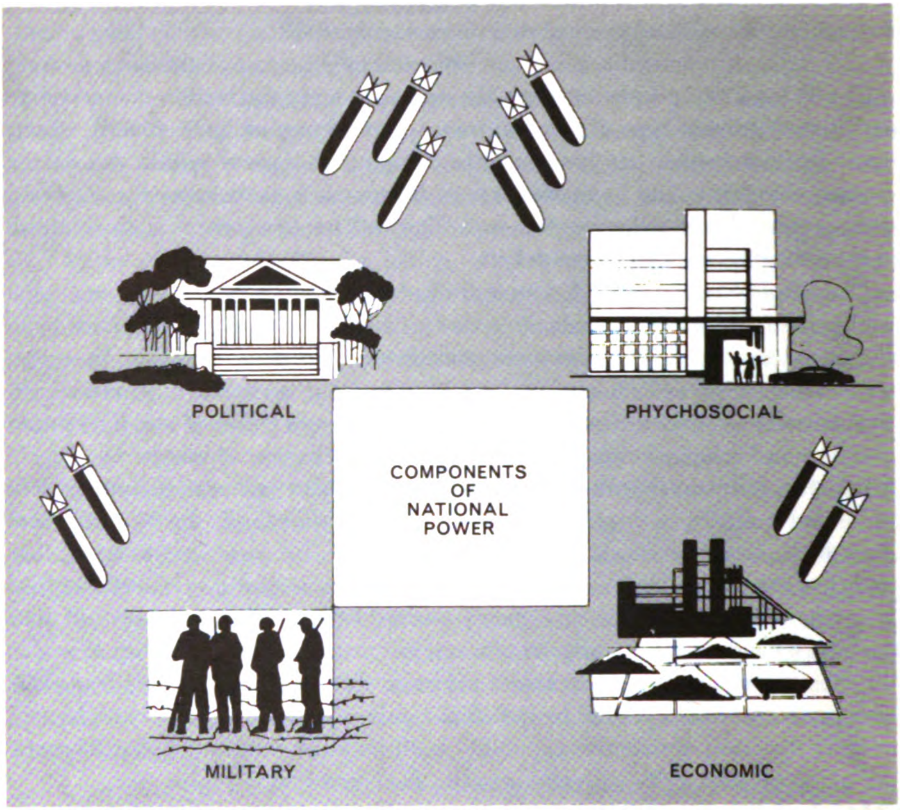


FIGURE 78. Targets within a nation.

mine one or more of the others, so closely are all the components of national strength related.

It was discovered after World War II that if the Allies had concentrated a larger percentage of their bombing efforts againts the Nazi electric powerplant system and against the interdependent synthetic oil, synthetic rubber, and the principal chemical industries, the breakdown of essential German war production could have been accelerated, and, presumably, the war in Europe could have been won much sooner. During the course of the war the Allies, of course, were not able to learn or properly evaluate all of the possibilities for strategic bombardment.

Military Structure

U.S. Air Force leaders have made it amply clear that this Nation's No. 1 target priority is the enemy's military forces and war-making potential. In the words of Gen. Curtis E. LeMay, this objective can be achieved "through selective application of firepower against enemy airdromes, missile sites, radars, communications networks, and other military targets—wherever they may be."

The logic behind the high priority assigned these targets rests on the fact that unless the military forces are destroyed they can retaliate. Other targets can wait their turn. Potential enemies, no doubt, have assigned their highest priorities to our forces and similar installations.

The military structure of a nation consists of personnel, combat and support equipment, the logistic support system, and a strategy for employment. Superior numbers of troops and great quantities of combat equipment in themselves do not necessarily mean military strength nor do they in all cases constitute a threat to other nations. In the matter of numbers of troops, for example, consider the case of Communist China. Red China has an estimated 2,500,000-man army with a 10,000,000-man ready reserve and, because of the great population, could probably summon an army of 60,000,000 men in a very short period of time. Yet of the two major Communist nations—Communist China and the Soviet Union—the latter is considered much the stronger at the present time. The reasons for this rating are rather elementary. Communist China lacks the weapons and technological development to go with its immense manpower strength. Thus the comparative military strength of nations is largely determined by how well their equipment measures up technologically with others and how well the people are trained to operate the equipment.

For targeting purposes the military forces of an enemy can be grouped into two categories: those that give the enemy the capability to win the war and those that give him merely the capability to wage war. Military forces included in the first category are those that threaten the survival of another nation and the survival of that nation's military forces. Enemy air forces with the range to strike the United States present a constant threat to our national survival. These air forces consist of aerospace vehicles, bases or launch sites, personnel, weapons, and control facilities. Under certain conditions enemy ground and naval forces may present a major threat. This danger is primarily dependent upon the location of the force, the type of force, and its firepower delivery capability. Submarines and surface vessels might well disrupt or destroy our sea transport and serve as launch sites for missiles. Ground forces with superior strength could possibly overrun and destroy our ground forces and occupy the territories of our allies. Enemy forces with the capability of winning a war must be assigned the highest target priority.

Lower target priorities go to those enemy forces which contribute only to the enemy's ability to wage war. This distinction can be made on the basis of such factors as location, size, performance limitations, and firepower delivery capabilities. For instance, a large body of ground troops with all its weapons intact but cut off from a fuel supply which would permit it to move rapidly and over long distances might fall into the second category. This force would be able to wage war within the area the troops could reach on foot and within the range of its weapons, but unless it were close enough to constitute a survival threat, it could be assigned a lower target priority. Since forces such as these present no immediate threat to national survival or to the attainment of military objectives, they need not be reckoned with in the initial attacks.

Economic Structure

Among the systems that contribute to a nation's ability to prepare for and sustain war, the economic structure is often the most important. The ability to wage war depends upon the capability to produce or to acquire the physical weapons of war such as guns, rockets, explosives, tanks, air vehicles, and fuel.

When analyzing a nation's economic strength from a munitions standpoint, we can divide it into four broad categories: raw materials; basic processing, component parts, and equipment industries; end products industries; and basic services and utilities.

RAW MATERIALS.—To support its wartime economy, a nation must possess an abundance of natural resources or acquire needed raw materials from other nations. Natural resources are the forces, materials, and reserves in the natural environment of man that can be exploited industrially or commercially. Mineral deposits, forests, waterways, and farmland are categories of natural resources.

FIGURE 79. Application of target intelligence: heavy end-product industrial plant destroyed at Pyongyang, Korea, 1950.

Some of the raw materials are coal, oil, rubber, wood, foodstuffs, iron ore, and copper. Some of these materials—iron ore and crude oil, for instance—must be either within the confines of a nation or so located that the nation can import them in huge quantities all through the war.

BASIC-PROCESSING INDUSTRIES.—The basic-processing industries change the form or nature of raw materials so as to make them more usable. The process is essentially one of conditioning. Some of the products are timber, leather, textiles, cement, pig iron, light metals, and metal alloys. Basic industries also include plants producing equipment and parts, such as bearings, industrial transportation equipment, and machine tools.

END-PRODUCT INDUSTRIES.—End-product industries are those that subdivide a raw material into several products or combine conditioned materials into finished products sent directly to the consumer. Some end products are air vehicles, automotive equipment, clothing, weapons, ammunition, and petroleum products (Fig. 79).

BASIC SERVICES AND UTILITIES.—These are the plants and facilities that provide electric and steam power, heat, transportation, communications, and food services.

In the eyes of the average citizen his nation's war industry means the finished-product plants that turn out the tools (hardware) used in battle—the airplanes, guns, tanks, ships, and ammunition. But to the mobilization planner, the military logistician, and the air operations planner, it is the sum of the economic structure. Each component of the industry is essential to the nation's war effort, and the destruction of any one component would surely stop the flow of war materials to the fighting forces. This does not mean that we should try to destroy or neutralize a complete industry nor that in all cases we should strike directly at a plant whose product we want to eliminate. Sometimes an end-product industry can be put out of operation more efficiently by striking a basic service that furnishes utilities to that industry. As pointed out earlier, the entire electric power plant system of Germany was not attacked, yet the loss of more than 100 plants could have caused the collapse of that country's economy.

By June 1944 the once highly mechanized, swiftly moving German Army had been reduced to fighting a defensive war. It had been denied mobility. This was due partially to Allied attacks upon the German petroleum industry, but mostly to attacks upon German transportation. By the autumn of 1944, German transportation, repeatedly hit, had become critical. The conditions prevailing after January 1945 led to catastrophe. Industry could not get coal from the mines, yet most powerplants and gasworks were coal-fired. Consequently, industries depending upon electricity and gas were slowed down or shut down. Industries could not get raw materials. Only those parts necessary for completing equipment already partly assembled were shipped. Then it was difficult to move this completed equipment forward to the German Army. Today we have the capability to bring about this condition in hours, rather than years.

In Japan our World War II intelligence at first underestimated the critical nature of that country's transportation system. Later we found that strangula-

tion of that system would have destroyed Japan's economic structure. Lack of transportation would have reduced Japan to a series of isolated communities. Food could not have been moved. The Government would have been incapable of rapid large-scale movements of military forces and munitions.

In a prolonged war it was enough to cut off an enemy's source of raw materials to create a strategic shortage. In a nuclear war, obviously, it may be necessary to abandon some of the principles which apply in a prolonged war. Nevertheless, the categories into which an enemy's economic structure may be divided are still valid considerations for assessing the enemy's economic strength. And until it is certain that the economic structure has been rendered incapable of sustaining enemy forces, it will remain a high-priority target in the event of war. With nonnuclear weapons it was possible to fight a defensive war over a long period of time in the hope of building up the economic structure to support or to reinforce the military structure. With nuclear weapons it is doubtful that such a defensive war would be possible. Many strategists believe that the next major war will be fought with the stockpiles of weapons existing at the outbreak of hostilities. If we accept this viewpoint, we must concede that the economic structure is more important before a war than after the war begins. The assumption is that an attack with nuclear weapons will so disrupt a nation's economy that the war would be won or lost before a devastated economic structure could be rebuilt.

Political Structure

The political structure of a nation comprises the governmental and administrative bodies that control, coordinate, and direct the entire national effort. Government leaders must decide how to prepare for the eventuality of war, how to destroy the enemy in the event of war, and whether and when to go to war. They must decide upon the balance of interest between the military, civilian, and foreign aid budgets. They must also decide upon the division of resources between the armed forces and the civilian population. In short, the governing body of a nation makes decisions for the people, transmits these decisions to the people, and, finally, executes these decisions. This ruling body and the machinery through which it operates make up the political structure of a nation. The political structure galvanizes a nation into action and causes it to function as a cohesive unit.

In past wars, before the advent of aerospace power, the political structure was fairly invulnerable to direct attack, mainly because there were few tangible targets. These targets were limited to government buildings or other ruling or administrative objectives with questionable military value. The mere destruction of planning offices, files, and administrative buildings would no doubt disrupt the efficient operation of the government; however, such destruction would have little effect on the enemy's war-making capability. Probably the greatest effect would be a psychological one on the mass of the population. Nevertheless, there have been times when political structures have been profitably attacked. The World War II British bombardment of the Gestapo head-

quarters in Oslo is an example. Destruction of German files and personnel aided the underground and encouraged Norwegian resistance.

The ultimate to be gained from direct attacks on the political structure would be destruction of office buildings and governmental officials at the same time. An attack failing to do both would have been better expended on other targets.

A government is most vulnerable in its relations with the people, for it must control their actions and it must have their support. Consequently, it has been determined that the most effective attacks against the political structure would most probably be indirect assaults. One of the most profitable of these indirect assaults would be against the communications system. Because the government must communicate with the people and within itself, and cannot, in fact, exercise control over the nation without such contacts, the attacks on the communications systems would be felt immediately. With its communications systems destroyed, a nation would soon cease to function as a cohesive unit. A communications system, for instance, would be an especially productive political target for nuclear weapons, since a relatively small number of weapons could destroy the key elements and keep them out of commission for a long time. The resulting confusion would overlap into all other components of the national structure.

Psychosocial Structure

The psychosocial structure of a nation includes the moral strength of the people as manifested in their internal stability, unity, national will, and ability to influence other people. For purposes of target study, the psychosocial structure of a nation or people is often reduced to terms of morale, because morale is something that can be sensed, observed, and influenced.

Before any action designed to influence the morale of the population can be taken, it is necessary to study the population's psychosocial structure. Unless it is harnessed to a strong war machine, high morale in itself has little value; conversely, a strong war machine coupled with poor morale would mean little. On the other hand, both high morale and a strong war machine make a formidable combination; each gains strength from the other. This is not to say that the mutually supporting elements of high morale and military strength are invulnerable to psychological attacks. Following a proper analysis of the state of morale and the military machine of a nation, targets and methods can be selected that will affect that particular combination.

In past wars the morale of the people was an important factor in a nation's ability to fight, since upon it depended the production of materials needed for continuing the war. In fact, in past wars the possession of enough raw materials, industries, and skilled personnel did not necessarily mean adequate quantities of war materials. These had to be produced. Production required efficient organization and direction, cooperation among all the people, their willingness to consume less and produce more, to devote their energies to the production of war materials at the expense of consumer goods, and at the same time to face personal hardships, tragedies, and the dangers of war. In past wars, therefore, if

the morale of the people could be weakened, the enemy was deprived of his full war potential.

Some of the conventional targets for morale attacks have been water supplies, food supplies, housing areas, transportation centers, and industrial sites. The objectives of these attacks in the past have been to dispel the people's belief in the invincibility of their forces, to create unrest, to reduce the output of the labor force, to cause strikes, sabotage, riots, fear, panic, hunger, and passive resistance

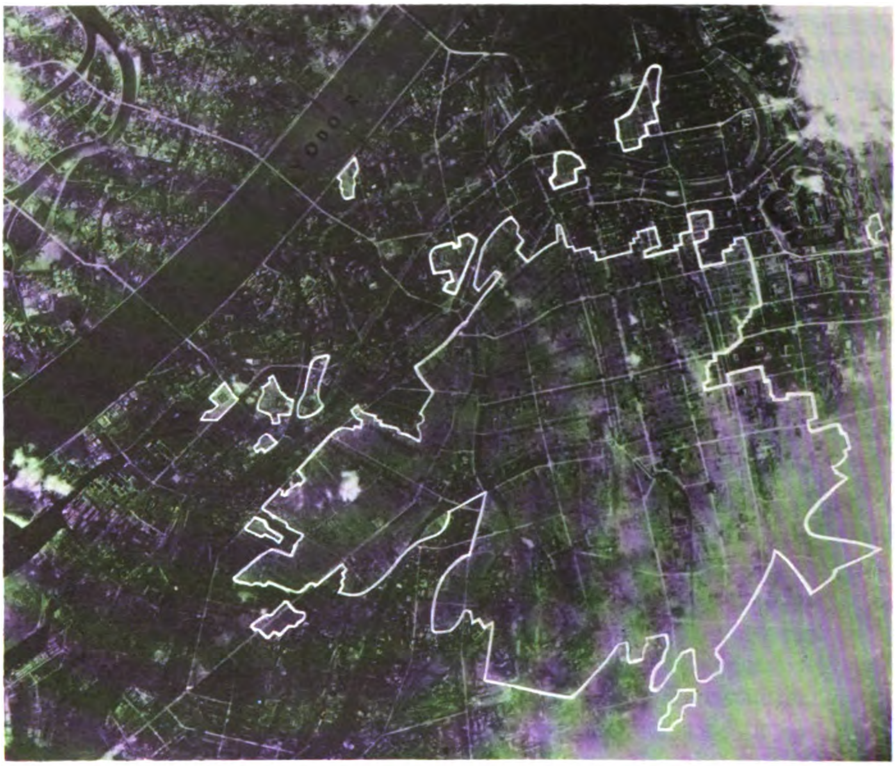


FIGURE 80. Strike photo shows extent of damage after a B–29 raid on Osaka, Japan during World War II.

to the government, and to create a general feeling that the war should be terminated. Although the question of how far the will to resist of a given group of people could be weakened or destroyed by aerial bombardment with conventional weapons was debatable, it was an irrefutable fact that a labor force preoccupied with civilian defense duties and the finding of food, shelter, and transportation could not operate at peak efficiency in the production of the materials of war (Fig. 80).

Nuclear weapons have changed many concepts of war, including the concepts for attacking the psychological structure of an enemy. What are some of these

changes? The Soviet Union continually uses the relative safety of the cold war to attack—with words and deeds rather than with bombs—certain psychosocial targets in democratic countries in advance of possible hostilities. The Soviets have, for example, been accused of imposing on Western European countries nuclear blackmail, which has in turn induced a certain amount of nuclear hypertension in the people of the rest of the world. The general effect, however, could work to the disadvantage of the U.S.S.R., since these attacks, while they may have caused a great amount of fear, indecision, and uncertainty, have in general increased the determination of free nations to develop new weapons, new methods, and new countermeasures to offset the threat. In addition, nuclear blackmail may have had a reverse effect in inducing nuclear hypertension in the people of Communist countries.

In any prolonged war, whether fought with nonnuclear weapons or with low-yield nuclear weapons, the concepts for attacking a nation's psychosocial structure—concepts which were developed in recent wars—would generally be applicable. But if we were to search for the single type of target whose destruction would have the greatest adverse effect on the morale of a population today, we would have to conclude that the destruction of an enemy's major cities with high-yield nuclear weapons would produce the most telling results, not only on morale but on every other component of the nation's structure. However, if the objective of first destroying the enemy's military forces can be met, the deliberate destruction of cities should not be necessary.

The ability and will of a nation to wage war depend on a combination of military, economic, political, and psychosocial strengths. Attacks against any one of these strengths will have an effect on one or more of the others. In the study of a nation's structure it is necessary to recognize this interdependence and to select targets that will create the greatest adverse effect on the enemy's ability and will to wage war. Therefore, the first order of the day must be to know the enemy.

STRATEGIC AND TACTICAL TARGETS

By definition, a strategic target is any installation, network, group of buildings, or the like, considered vital to a country's war-making capacity and singled out for air attack; and a tactical target is any physical object, person, group of persons, or position singled out for attack during the course of battle or tactical operations in order to reduce, or to destroy, the enemy's ability to sustain his combat operation. Most targets will fall into one or the other of these general categories, with finer distinctions made within them. However, there are no immutable definitions which will place each target in one category forever. In fact, some targets may be correctly placed in a number of categories during the course of a war or campaign, and some may even be correctly identified as lying within two or more categories or subcategories as the same time.

Strategic Targets

The strategic targets of the U.S. Air Force are implicit but not explicit in the mission of the Strategic Air Command. This mission is relatively simple in con-

cept and, as a result, fairly well understood. The Strategic Air Command has the basic mission of massive retaliation at the heart of the enemy country in the event of total war. All of SAC's aircraft and missiles have preassigned targets in the command's emergency war plan. Target priorities do not, however, remain fixed. They change constantly as different target complexes become more strategic; that is, as they become more important to the enemy's war-making capacity. Although there is always a shifting of targets, the target system itself is arranged in order of priority. In other words, Air Force planners know which target or targets would be hit first if only a limited number of bombs or missiles could be released. Gen. Thomas S. Power, speaking as SAC Commander, told a congressional committee:

> On our most important targets we have to tailor the yield to the size of the target and the highest degree of probability of success. All our weapon systems even today are competing for each one of these targets in their order of priority. . . . There is a formula now in being that we apply against this.

In answer to a question from a Congressman, General Power replied:

> We have all the target systems in Russia covered that we are capable of reaching. Of course there are qualifications. It depends upon how much force I have. If I generate the whole force I can reach so many targets. If I operate under the condition of retaliation where I get only the alert force off, then it is a much smaller number. But I have the capability to reach any target in Russia.

Data concerning specific targets to be hit are highly classified, but it is no secret that the Soviet Union, in building a powerful arsenal of long-range ballistic missiles, intends the targets of these missiles to be the fixed airbases of our deterrent force and our missile bases. Our targets would logically have to be the U.S.S.R.'s missile sites, aircraft, and supporting elements.

A misconception about nuclear weapons needs to be clarified. "Too often when strategic nuclear weapons are discussed," said Gen. Thomas D. White, speaking as Chief of Staff, USAF, "the picture that arises in everyone's mind is that of a multi-megaton blast which totally obliterates everything within a large area. But this is not necessarily the case." The Air Force has expended much effort in its nuclear testing to develop small-yield weapons suitable for lesser tasks. The Air Force thus has the capability of destroying with one missile or bomb relatively small, but important, military targets which formerly would have required hundreds of aircraft sorties. It is clear that it is not this country's intention to saturate enemy target areas indiscriminately with high yield nuclear bombs.

Tactical Targets

U.S. tactical air forces, both in this country and at overseas bases, form a powerful combat element. In the event of general war, deployed tactical forces will automatically provide a nuclear strike capability against great numbers of preselected targets and will take part in the counter-nuclear and counter-air battle. Their targets will have been generated not only by our own needs, but also by the requirement for protecting and preserving the political and military integrity of our allies. These strikes will also serve the extremely important

function of enhancing the probability of successful penetrations and withdrawals by our strategic forces.

The overseas tactical air forces are maintained in the same alert posture that our strategic units provide worldwide. Tactical fighters and surface-to-surface missiles, dispersed throughout the overseas theaters, are poised with the same around-the-clock readiness, and are prepared to strike their targets on a moment's notice. Tactical air forces are equipped with both high-explosive and nuclear weapons, giving them the capability to apply the right amount of force against the desired targets. Their crews are highly trained and dedicated to the job at hand. The fast and deadly power of these forces, which in many cases are based within minutes of enemy territory, can provide substantial contribution to the overall offensive.

U.S. tactical air forces in a theater of operations have three primary targets. They are the enemy's aircraft or missile delivery capability; enemy supplies, ammunition, and so forth, in the rear battle areas; and targets within the battle area itself in support of our own troops. These targets, when translated into tactical employment tasks, go by the time-honored names of gaining and maintaining control of the air, interdiction, and close-combat air support.

SOURCES OF TARGET INTELLIGENCE

In 1959, Gen. Thomas S. Power, SAC Commander, told a congressional committee: "One of our weakest areas is the little information that we have to work on. If there is anything that needs emphasis in this country, it is the ability to get more information about the Russians, and particularly their missile capability and their position in the missile race." Without detailed and accurate knowledge of its enemies, a nation cannot fight a war successfully. This has been taught by the experience of every war, but it is sometimes overlooked. The exigencies of the nuclear-missile age have ordained that the area of target intelligence can never again be neglected.

Long-range bombardment operations early in World War II indicated the need for three categories of information: target information, enemy capabilities and intentions, and friendy capabilities and intentions. These basic requirements have not changed with the advent of nuclear weapons. This section of the chapter will be concerned primarily with target information.

Although nuclear weapons have not changed the need for target intelligence, there have been changes in the specific types of information required. For example, the need is great for a more accurate mapping of the world, because some areas of the world, e.g., Communist countries, are not accessible to outside surveyors or map makers. Such information must be obtained, if it can be obtained at all, from intelligence sources. This problem has been outlined by Maj. Kenneth A. Smith in an article entitled, "The Ballistic Missile and Its Elusive Target," which appeared in the Air University Quarterly Review, Spring 1958:

> For hundreds of years mapmakers have been attempting to pinpoint one . . .

place in relation to others across the face of the earth. The slight inaccuracies have always been an annoyance to navigators, but until recently the slow speed of the means of transportation allowed ample time to correct for the errors. With the coming of high-speed long-distance aircraft the difficulty became somewhat aggravated but still there was some time to make computations and a crew was along to correct navigational errors by taking visual sightings. Even in bad weather the radarscope or radio and radar navigational aids were available to the crew. With all these checks available the error to worry about was the human error of the navigator rather than the reference errors in the maps.

But with the coming of the ballistic missile the problem suddenly assumed critical importance. All traditional navigation devices for correcting map errors have no use here. The only things that matter are the validity of the information set into the guidance system before launching and the faithfulness of the missile's guidance system in keeping the missile on its trajectory. Of course such a system assumes that the location of the target in relation to the launch pad can be plotted precisely. It is this assumption that we must make come true by finding means to link our North American datum system to those for other continents. This is one more science in which we are operating under an informational handicap, for the details of the North American datum have been available to the rest of the world, including Russia, while considerable detail from the Russian datum has not been available to us. Presumably the Russians have been able to tie their datum into ours and can now pinpoint targets on this continent. We do not necessarily have to have their information to achieve the same accuracy ourselves. We do need more geodetic data than we have as well as more detailed information on the location of targets. But with some additional geodetic data there are methods that will enable us to extend our own datum system to cover other continents.

Collection, Analysis, and Dissemination of Target Information

In the midst of the early 1960 controversy which sprang from Secretary of Defense Thomas S. Gates' statements that the alleged missile gap was being examined on the basis of new intelligence estimates, the American public learned a great deal about the collection and evaluation, and to some extent the dissemination, of intelligence data. Allen W. Dulles, Director of the Central Intelligence Agency, said in a speech that the United States collects a great deal of its intelligence information about the Soviet Union by means of electronic techniques. This was summed up in the New York Times for January 31, 1960:

> The United States has ringed the Soviet Union with a variety of radar instruments that can observe launchings from missile test centers and other significant aerial movements. It uses powerful and sensitive electronic devices to listen in to radio wave lengths in the Soviet Union.
>
> In addition, intelligence experts study such material published in the Soviet Union—train schedules, newspapers, books, scientific journals, reports of party meetings and theatre programs.

These methods stand apart from the undercover or covert means of collecting information, about which more will be said later.

Intelligence data flows daily into a central headquarters in Washington, D.C., where it is sorted, catalogued, studied, and evaluated by intelligence experts from the agencies affiliated with the U.S. Intelligence Board. Through this process the official estimates of a given situation are formed.

The key organization in the U.S. intelligence effort is the Central Intelligence Agency (CIA), which coordinates the work of all the other collection agencies. The director of the CIA also presides over the U.S. Intelligence Board. This Board is composed of intelligence representatives from the Department of State, Department of Defense, the Army, the Navy, the Air Force, the Federal Bureau of Investigation, and the Atomic Energy Commission. These representatives have responsibility for analyzing intelligence data and preparing memoranda and estimates covering worldwide military, political, and economic trends which bear on the Nation's security. They analyze all relevant intelligence collected by or available to all agencies of the Government.

As can be seen, the Air Force collection effort is but one part of the overall intelligence program, but the Air Force in turn has available to it, through the U.S. Intelligence Board, the distillation of the efforts of all the other agencies.

Air intelligence officers usually need intelligence concerning targets, bomb damage, and enemy defenses; air orders of battle; subversive activities; enemy political, economic, social, and psychological situations; and escape and evasion. They also need background material on foreign countries and their leaders. The volume of intelligence needed on these subjects is determined largely by the mission and the level of command of the air unit concerned. Naturally, the squadron or group intelligence officer does not have the same requirement for intelligence on subversive activities or on economic, political, and social developments as does the officer in the Directorate of Intelligence who briefs the Air Staff. At higher headquarters the intelligence officer can use a variety of sources within his own headquarters, as well as those of other military and Government agencies. Most governmental and civilian sources are not directly available to units at levels below theater air or major commands. Information is therefore usually secured through top command levels and disseminated to lower units as required.

Photointelligence

One of the most important methods of collecting target information is through photointelligence. More than three-fourths of all combat intelligence used in World War II and the Korean conflict was derived from this source. Aerial photography is generally reliable and usually provides the most up-to-date information available. Improvements of the past few years have made it even more valuable than ever. Radarscope photography is one of these improvements, and, if advance expectations prove out, photointelligence of one sort or another can be provided with earth-circling satellites.

Importance and Advantages of Photointelligence.—The use of aerial photographs as a source of intelligence acquired tremendous importance as a result of World War II and Korean experiences. The verbal or written intelligence report depends upon the accuracy of observation and the memory of the informants, as well as on their ability to accurately record or express the report. The camera is the only device that can collect and record detailed, documentary information in such a quick, timely, and efficient manner. Photointelligence does not, however, eliminate human error completely, since the pictures obtained can

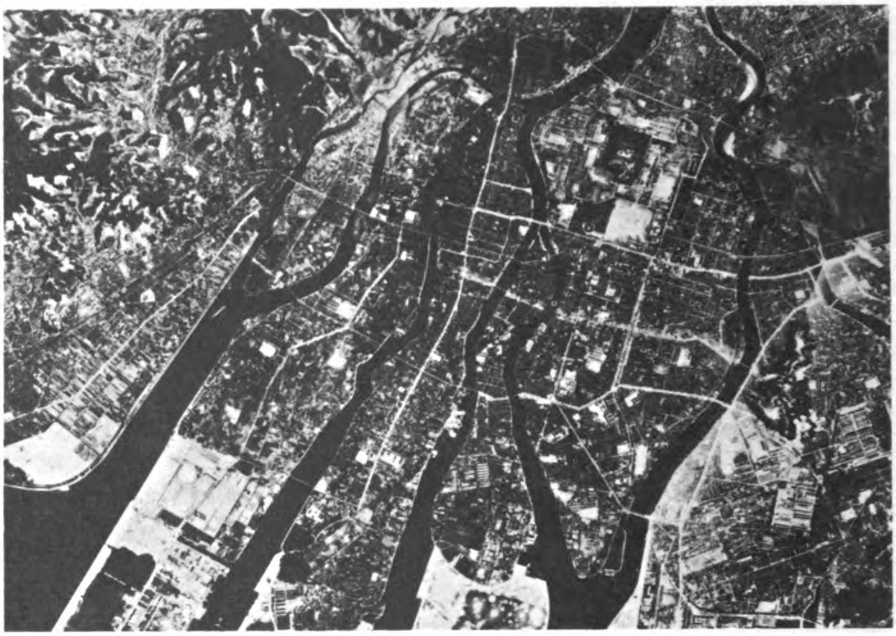


FIGURE 81. Before atomic bombing in Hiroshima, Japan.

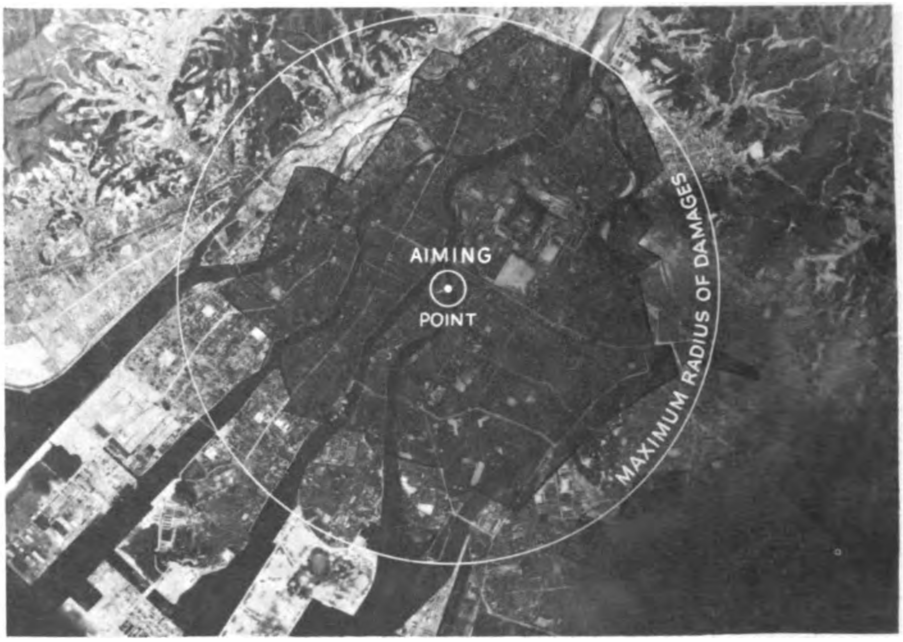


FIGURE 82. After the atomic bombing of Hiroshima, Japan. Total damage is shown within the circle.

be reliable source material only if the human collector supplies complete and identifying data with all photography (Figs. 81 and 82).

Perhaps the single most important military advantage of photointelligence over other intelligence products is that its chief source, aerial photography, can be used to collect information over otherwise inaccessible areas. However, this is only one of many advantages.

A singular advantage of the photograph is that it is a permanent record of the vast amount of detail which can come within the camera's view. A photograph is unprejudiced and literal. Moreover, it is reproducible, permitting it to be studied and restudied for various purposes and by different users. This is an informational source which can later be systematically interpreted and evaluated. By means of the photograph, a firsthand impression of the target is made available to the expert who is best qualified to interpret it, although that expert may be many miles away. The quality of being both a permanent and visual record of information permits the comparison of new material, detail by detail, with earlier photography of the same subject to provide comparative intelligence.

Aerial photography has the added advantage, under certain conditions, of providing more precise data about location and more accurate measurements than other means of observation. For example, aerial photography may be used to relate widely separate features which would be beyond the view of a ground observer. It is true that the ground observer can, on occasion, provide much more detailed information about a very limited area than can be furnished by the aerial photointerpreter. However, unless he has a measuring device, the ground observer may be less accurate in reporting dimensions and slope, and he may not be able to pinpoint the area accurately on a small-scale map.

PHOTO-RADAR INTELLIGENCE.—With the advent of radar in World War II, an entirely new area was opened up in the photointelligence field: photo-radar reconnaissance, which consists of radarscope photography and interpretation. In this discussion we are concerned only with the airborne (air-to-ground radar) phase of radar intelligence. Radarscope photography is different from visual photography in that it is obtained by the use of automatic cameras mounted on the radarscope set to take pictures of the face of the scope at desired intervals. The radar operator maintains a log showing the position of the aircraft at the time the photos are taken. The photographs are then processed and interpreted by photo-radar intelligence officers.

Radarscope photographs have the advantage of not being affected by haze, smoke, normal cloud formations, or darkness, all of which often render visual photography useless. However, radarscope photographs lack the detail of visual photographs, and pictures cannot be taken through dense rain and/or cumulonimbus clouds.

Radarscope photographs furnish operational data to be used as radar navigational and radar bombing aids, just as visual photographs are used as visual navigation and bombing aids. Photo-radar intelligence is used for the following purposes:

1. To select the most suitable route to the initial point and from the initial

point to the target. According to the United States Air Force Dictionary, the initial point (IP) is "a point on the ground, identified visually or by electronic means, over which an aircraft begins a bomb run, a run over a drop zone, or the like."

2. To prepare radar navigational maps and charts.
3. To prepare radar target charts and approach strips.
4. To determine the targets that may be successfully attacked through the use of radar.
5. To conduct briefings of crews.
6. To evaluate bombing-run results during periods of restricted visibility and at night.
7. To provide material for radar study classes and training.

Other Sources of Target Information

Intelligence information is collected from both overt and covert sources. Strangely, perhaps, by far the greater amount is collected by overt means.

Many sources of intelligence information and many collecting agencies contribute to intelligence requirements. Of these sources and agencies, some are active in peacetime, some in wartime, and others are active continuously. The sources most commonly associated with Air Force personnel and activities include combat crews, escapees and evaders, prisoners of war, captured equipment and documents, and aerial photographs. Other sources of valuable Air Force information include refugees, repatriates, disaffected peoples, press and radio, maps and models, weather maps and forecasts, guerrillas, agents, and air attaché systems.

OVERT SOURCES.—Valued sources of intelligence information not directly associated with the military, but which operate continuously, include the Library of Congress; the Departments of Treasury, State, Justice, Interior, Labor, Agriculture, and Commerce; the Civil Aeronautics Administration; the Central Intelligence Agency; the International Cooperation Administration; and the Maritime Commission.

Still other valuable sources of information which are not official agencies but which can contribute information are the National Committee for Free Europe; libraries and research centers of universities and their professional staffs; and large commercial corporations, such as oil companies with international interests. There are certain other cultural and philanthropic international organizations that can add to the basic, factual information from which strategic intelligence is derived.

Equally important as a daily source of information are the news agencies. TASS, for instance, the news agency for the Soviet Union, has long been a very active collector of intelligence information in the West. These nonofficial sources, however, do not provide information ordinarily considered military; instead, they provide social, historical, and cultural information which usually makes a major contribution to national strategic intelligence. Also important are such sources as printed materials from civilian agencies and patent offices, scientific and technical publications, and trade journals.

The importance of overt, unclassified sources of information to intelligence activities cannot be overemphasized. Many organizations, universities, and corporations have for years gathered information about the entire globe and its cultures solely for their own requirements or simply to assemble knowledge. The intelligence officer finds that these are fruitful sources with which to augment his own collection activities. These sources are especially valuable for the collection of strategic intelligence.

The importance of overt sources becomes even more apparent when we realize that the information gathered by research centers, organizations such as the Ford and Rockefeller Foundations, endowed museums, anthropological studies, and social research studies required years and millions of dollars to collect, and that a large part of it can no longer be duplicated. Much of this information is available to intelligence officers upon request; this ready availability often provides a prompt answer to strategic requirements.

While many agencies possess and continually collect intelligence information which is incidental to their own requirements, some agencies are organized specifically to collect intelligence information. The air attaché system, for example, occupies an important place in overt collection activities.

Air Attachés.—Air attachés are representatives of the Secretary of the Air Force and the Chief of Staff, USAF, and are members of the United States diplomatic staff in the countries to which they are accredited. They report information of interest concerning the countries to which they are assigned. They collect the information openly and by normal observation in the course of their duties. This practice is recognized and approved by the country to which the attaché is accredited.

Air attachés are assigned throughout the world where a need exists for the interchange of courtesies and information between air forces. Current requirements determine the number and location of attachés, but they are freely exchanged when mutual benefit will accrue to the countries that they represent and to the countries to which they are accredited.

Because of the obvious desirability of remaining persona grata in the country to which accredited, air attachés do not engage in covert intelligence activities. The exchange of military representation is a mutual act of courtesy and, in the interest of good relations, is not often jeopardized.

Covert Sources.—Clandestine collection activities are sometimes necessary when the security of a nation is threatened. They may involve the development of a core of professional informers who secretly conduct collection activities within the area upon which they report. Covert activities in the past have been most prominent in time of war. Even though these informers are not always reliable, the increasing tenseness of the world situation has forced many nations traditionally opposed to this type of intelligence collection to turn to it as a means of preventing military, as well as technological, surprise. Some informers—for example, Pontecorvo, Burgess, and McLean—have achieved spectacular notoriety. Yet the risks involved in their operations and the security restrictions imposed upon them make the world of professional informers a dangerous place

in which to reside. One has only to consider convicted atomic bomb spies Klaus Fuchs and the Rosenbergs to realize the magnitude of this danger.

LIAISON.—Well-established liaison between reliable agencies is one of the best methods of accomplishing the intelligence mission. Each agency, regardless of its coverage, will sometimes not have the facilities or equipment to accomplish desired results expeditiously. An agency will find that other agencies or services may well be in a position to help.

It is reasonable to expect agencies to become familiar with the operations of other agencies that are active within the same geographic and subject areas. The appointment of one person to act as a representative to related agencies or organizations is usually the most effective method of establishing desirable liaison. Such liaison also tends to ensure that agencies do not become involved in matters for which others are primarily responsible, thereby depleting manpower resources as well as interfering with the missions of other agencies. Liaison, while sometimes difficult to establish, tends to ensure that two or more agencies or organizations do not endeavor to exhaust the same source, causing double or triple expenditure of funds where one expenditure by the agency of primary jurisdiction is sufficient.

COUNTERINTELLIGENCE AS A SOURCE.—The missions of intelligence collections and counterintelligence have been said to be inseparable, since, in addition to the security which it provides, counterintelligence is concerned with collections of its own.

The chief mission of counterintelligence is to destroy or minimize the effectiveness of the enemy's intelligence system by (1) denying information to the enemy through security measures, camouflage, and concealment; (2) giving false or misleading information to the enemy by means of ruses, demonstrations, and displays; and (3) countering the enemy's sabotage, propaganda, or other subversive activity designed to interfere with the accomplishment of our own established missions.

A frequent misconception regarding counterintelligence is that it is concerned only with matters such as sabotage, espionage, disaffection, treason, security violations, and disloyalty. These activities constitute only the defensive phase of counterintelligence; but there is also an offensive phase, which seeks to gather information from points as close to the source as possible. The greatest contribution that counterintelligence makes to intelligence collection is in its pursuit of the offensive phase. In an effort to achieve their own objectives, counterintelligence forces collect much information of primary interest to activities other than counterintelligence. Intelligence collection efforts may therefore lean heavily on counterintelligence, not only for security but also for information and sources to support the complete collection effort. Although counterintelligence in the U.S. Air Force is a function of The Inspector General's office, it should be thought of not as something wholly apart from other intelligence activities, but as a most reliable source providing substantial support to the collection operations of intelligence units.

RECONNAISSANCE AS A SOURCE.—The combat intelligence officer or the

FIGURE 83. Photo interpreter examining aerial photo map with a third dimensional viewer.

cartographer requires intelligence that cannot be categorically identified as coming from either covert or overt sources; this is intelligence derived from reconnaissance. Such intelligence usually relates to a rather well-defined area about which there is a need for exact information, such as the disposition of friendly and enemy troops or air units, locations of material or equipment, terrain, and cultural or physical features. To collect such information, the intelligence officer turns to aerial reconnaissance and aerial photography as primary and reliable sources of information. Aerial reconnaissance can also be a reliable means, within certain limitations, for augmenting background information furnished by other agencies. Aerial photography is supplemented by visual observations, as well as electronic methods.

Aerial reconnaissance and aerial photography, like the covert activities of the professional informer, traditionally have been identified as wartime activities. Since the end of World War II, however, and particularly as the tensions of the cold war have become more intense and as technological developments of the nuclear age have expanded the war potential of nations, these two have become increasingly important to the free world's intelligence-gathering mechanism. Strip mapping and infrared cameras which can take pictures from an altitude of 15 miles or higher and tape recorders which record radio transmissions and radar pulses, along with times of transmission and frequencies are invaluable as means of checking data collected by other means. Moreover, in the nuclear, aerospace age which is characterized by weapons with supersonic speeds and tremendous destructive power, aerospace reconnaissance and photography in peacetime are absolutely essential in guarding against a surprise attack, especially when a nation or bloc of nations attempts to shroud their military potential in secrecy. The importance and extent of peacetime aerial surveillance was underscored in May 1960, following the loss of a U.S. U–2 high-altitude reconnaissance plane in the Soviet Union.

The advent of nuclear weapons has increased rather than lessened the requirement for aerial reconnaissance. The need is great, for example, for reconnaissance satellites to assist in completing the accurate mapping of inaccessible parts of the world and to keep potential enemies under surveillance and report any warlike acts or preparations. In the event of general war it is presumed that such reconnaissance satellites could also prove invaluable in assessing the damage wrought by nuclear attacks.

Tactical commanders will also have a great need for aerial reconnaissance, and this variety of reconnaissance cannot be neglected. If war should be forced upon the United States, the tactical commander will face many grave decisions early in the air battle. Within a few hours he will have to appraise the result of his first strike against preplanned targets, evaluate the threat of enemy counterattacks, and establish target priorities for his second wave of attacks. Because of his limited resources in aircraft and weapons, the survival of his force, sector, or theater may depend upon his immediate decision. Unless he is assured of timely, coordinated, and high-quality aerial reconnaissance, he may have to act without essential facts or knowledge of alternatives and commit his resources by blind guesswork or instinct.

AIR TARGET MATERIALS

In 1947, as a result of World War II experience and in recognition of the necessity of having complete, up-to-date target information in advance of hostilities, the Air Force initiated a program of comprehensive targeting to provide operating units with adequate target intelligence in graphic and textual form. The new program was prompted also by the knowledge that target materials, such as maps and charts, which had been handed down in World War II target folders, varied in scale, topographic and cultural detail, color presentation, grid systems, sheet sizes, and marginal data. It is little wonder that commanders found the lack of standardization a serious disadvantage in orienting new crews; in planning, executing, and evaluating combat missions; in exchanging target materials among combat forces; and in conducting joint operations.

To implement the new program the Air Force authorized the establishment of target material production facilities by each of the various military commands and activities. While this arrangement produced a great amount of target materials, the program as a whole, which suffered from a lack of coordination, failed to produce all the target items required and resulted also in considerable duplication. In time, the worldwide targeting effort came to be regarded as two distinct and apparently unrelated programs. The use of the separate titles, Air Objectives Folder Program (AOFP) and Tactical Targeting Program (TTP), bore out this assumption. The use of different target numbering systems also emphasized the division of effort.

Thus, in order to ensure maximum target coverage from available production resources, the Air Force, in collaboration with the Army and the Navy, developed the Air Target Materials Program (ATMP). This program, implemented in 1956, permits the Assistant Chief of Staff, Intelligence, Headquarters USAF, to coordinate the production, maintenance, indexing, and reporting of air target materials to meet the requirements of all three of the military services. The ATMP establishes a system of priorities for the production of air target materials and ensures, through coordination, the most efficient use of available production sources.

Air target materials provide necessary intelligence in its most useful form. These materials are of two basic types—graphic and textual. They may be used in all phases of combat air operations from planning and training through the execution of the operation. Specifically, air target materials provide intelligence necessary for target analysis and selection, mission planning, briefing and debriefing, mission execution, post attack analysis, and damage assessment.

Graphic air target materials are charts, mosaics, illustrations, and combinations thereof used to present target intelligence. The intelligence presented and the manner of presentation will vary. Each item is designed to satisfy certain planning or operational requirements and to support one or more weapon systems.

Textual air target materials present supplementary target intelligence which cannot readily be shown graphically. However, they are usually keyed to graphic air target materials.

The best known products of the targeting program are target folders. Target folders provide a particularly useful method of filing air target materials. Actual contents of the target folder generally vary with the type of activity, and the method of filing may also vary. Usually, folders are filed either numerically by reference number or alphabetically by target name. Because of the need for maximum flexibility, no attempt has been made to standardize folders or filing in the ATMP. Regardless of the method chosen, it is extremely important that activities which maintain target folders act on information and instructions contained in ATMP publications, such as the Target List and the Target Change and Information Bulletin. In this manner, target folders are kept up-to-date and ready for immediate use.

TARGET SELECTION

Actual target selection is based on answers to two questions: What are the capabilities of the attacking force? What contribution will the attack make to the overall objective?

The first question concerns operational capability. The targets selected should be within range, be large enough to be struck effectively, and require no greater effort than the attacking forces are currently capable of delivering. One reason why the attacks on the German aircraft industry during 1943 and early 1944 failed to neutralize the German fighter force is that the combined resources of the Royal Air Force and the United States Army Air Forces were not large enough at that time to knock out the aircraft plants and to keep them knocked out.

The second question is principally one of intelligence. The attacker should make sure that the targets selected for attack will directly support his overall objective. For example, if he wishes to destroy the enemy's war-making potential, the attacker should select those targets that will be most effective in disrupting industrial military production. In other words, mere industrial destruction is not enough; he must concentrate on those targets that give the enemy a decisive capability.

Strategic target planners today must also be concerned with what amounts to a new consideration. This has come about because of the development of the means for applying an old principle of war—mobility—to the rather unwieldy ballistic missiles and their launching equipment. The versatility of Polaris submarines, missile-launching aircraft, and missile launchers on railroad flatcars has complicated targeting problems by setting critical strategic targets in unpredictable motion in three media. The problems of reaching and attacking fixed targets appear small compared to the problem of merely locating mobile targets. As a result of these fairly recent developments in weaponry, target planners must now consider whether the target is fixed or mobile.

A plan related to mobility is one proposed for deceiving, or "spoofing," the enemy as to the location of strategic missiles. This plan has evolved as a part of the "Minuteman" concept of deterrence and potential retaliation. It calls for a

large number of dispersed missile-launching sites through which a smaller number of missiles would be rotated often enough to prevent the enemy from knowing exactly where they were at any given time. For an enemy, the problems associated with attacking a single target complex of this type would be immense.

During the latter part of 1960 a Joint Strategic Target Planning group was formed at Offutt Air Force Base, site of Headquarters Strategic Air Command. This group, composed of representatives of all three services, and headed by General Thomas S. Power, CINC SAC, was given the task of examining strategic targets throughout the world, and assigning them to specific military organizations according to the capability of each organization. Certain targets were assigned to the United States Navy, for example, as appropriate for submarine-launched Polaris missiles; others were allocated for SAC's manned aircraft; still others were specified as targets for operational ballistic missiles. Since the capabilities and requirements will be continually changing, the work initially begun by this group in 1960 must be continually reevaluated, and appropriate target assignments and reassignments made in accordance with the latest findings.

TARGET ANALYSIS

The addition of nuclear weapons to the military arsenal created the requirement for a new planning function and a new staff planner. The function goes by the name of target analysis, or employment analysis, while the staff planner who accomplishes this task is called, understandably enough, a target analyst.

It is true that a certain amount of target analysis was necessary with the use of high-explosive weapons. Some special missions during World War II and the Korean conflict, such as low-level bombing attacks against dams, required careful preattack analyses in order to assure enough force to breach the structures. But for routine bombing operations, many commanders using high explosives often depended primarily on intuition for matching weapons against targets.

Nuclear weapons are so much more destructive, and their effects so much more complicated than high-explosive weapons that intuition has no place in their employment. Target analysis is a critical part of the planning that takes place prior to the hitting of a specified target with a nuclear weapon or weapons. This analysis provides a commander with the prestrike evaluation of a target or target complex in the light of an assigned mission to determine the best available weapon, yield, height of burst, and ground zero. It is, in fact, the efficient fitting of weapon effects to the target. It must be pointed out that target analysis deals only with that portion of a strike that will occur after the nuclear weapon has been released or the missile has been fired. In other words, the target analyst predicts what, in all probability, will happen when the weapon detonates. This is an important distinction which implies that the decision to hit the target has already been made. The decision to strike will have been made on the basis of a preliminary target analysis, but, once the target is selected, it is up to the target analyst to establish the most efficient means of accomplishing the mission.

Targets may be analyzed in a number of ways, all of which are based on a numerical system. The numerical system, which is used by specially trained target analysts, permits the assessment of the probable number of casualties or the determination of the percentage of damage to the target with a specified weapon. Through the use of a number of tools, such as probability charts and scales, plus current and appropriate intelligence data, it is possible to predict mathematically the results to be expected from hitting a certain type of target with a certain weapon.

The United States Army has found a disadvantage in the numerical system for frontline commanders in that the system is cumbersome and requires considerable proficiency in higher mathematics, as well as the use of a slide rule and a number of books, charts, and graphs. To meet the need for rapid target analysis by frontline commanders and commanders of small units, the Army has developed a system which utilizes in graphic form the data from the numerical system. The system makes use of atomic damage templates and is rather simple. The basic data obtained numerically is translated into lines on transparent acetate squares, or templates. Each template represents a single nuclear explosion of a weapon of known type and force, and shows the radius of effect of the explosion. These templates are shifted over the target areas plotted on a map until the proper template can be selected. Although this system makes the Army commander's task comparatively easy, the system in no way eliminates the time consuming and fairly complicated work necessary to produce the basic data for making the templates.

The Air Force System

The Air Force system to calculate probability of damage is called the Physical Vulnerability System, otherwise known as the PV system. To calculate the prabability of damage to a target from a certain weapon-carrier combination, a number of factors must be taken into consideration. It is first necessary to determine the vulnerability of the target elements. In other words, how hard is the target? The Air Force classifies targets as to their vulnerability in terms of Vulnerability Number (VN) and Vibration-Ductility (K factor). Every type target which has military significance is assigned a VN and K factor. The K factor is especially important because it takes into consideration the longer duration of the positive phase of the blast wave obtained from larger yield weapons. The higher the yield, the longer the duration of the positive phase. It has been found that a target can be damaged from a relatively low overpressure if the overpressure occurs over a long enough period of time. In the PV system, a "P" attached to the Vulnerability Number denotes that the target may be damaged by static overpressure (squeeze effect), while a "Q" denotes damage by dynamic pressure (wind effect). As noted earlier in the discussion of the physical vulnerability criterion for target selection, most targets will be subject to both "P"- and "Q"-type damage. These numbers, both VN and K, have been determined from Japanese experience, test data, and engineering analysis. The first step in an analysis is to find a VN and K for the target.

After this first step, the PV system is used to combine the vulnerability of the target, the extent of desired damage, the height of burst (HOB), and the yield of the weapon to obtain a weapon radius (WR). Thus the WR is not a single factor; rather it is the result of a proper combination of the Vulnerability Number and K factor with the yield and height of burst to produce a single parameter that is utilized in subsequent steps of employment planning. The PV system makes it possible to combine the weapon radius, distance from desired ground zero, and the circular error probable (CEP) of the carrier to obtain a probability of damage to the targets.

The Work of the Target Analyst

In order to perform his duties properly the target analyst must have up-to-date logistical and delivery data. These data include (1) weapons and yield available to the command, (2) delivery systems available, and (3) the support areas associated with each system. Not only must the analyst know what is to be used to start the weapon toward its target, but he must also know how much chance a weapon has of hitting the target. It is also necessary to have the best data available on expected attrition rates and time lags of the delivery means.

In addition to the logistical and delivery data mentioned above, certain other detailed data pertaining to the specific proposed atomic detonation must be made available to the employment analyst before he can properly analyze a target or target complex. These data include: (1) the size, shape, location, composition of the target, and how critical the target is to the enemy's continued prosecution of the war (these data must be obtained from intelligence sources); (2) the present concept of operations and proposed future operational plans, provided by the operations selection, so that the analyst may determine the future effect on these plans if obstacles to friendly movement should be created, or if fallout or neutron-induced gamma activity should deny areas to friendly forces; (3) the predicted weather conditions at the time of detonation in order that the analyst may evaluate how the weather might effect the damage done by the detonation; (4) the degree of risk the commander is willing to accept to friendly troops, delivery crews, military equipment, and installations; and (5) areas near the target where no damage is desired because of political, economic, or military considerations.


IBM

CHAPTER 9

ELECTRONIC WARFARE

Modern weapon systems place great dependence upon electronic devices for such duties as aiming ordnance or sighting bomb targets; communicating; guiding, controlling, or "homing" of missiles and aerospace craft; and reconnaissance. Where these electronic devices—many of them aggressive measures of warfare, so to speak—utilize electromagnetic radiations they are vulnerable to enemy interference, interception, or evasion; i.e., to electronic countermeasures. Elec-

◀ **From information contained on tape, a computer is capable of compiling thousands of answers and computations in seconds.**

tronic countermeasures include actions taken to prevent or reduce the effectiveness of enemy equipment and tactics employing, or affected by, electromagnetic radiations.

The technical and tactical exploitation of diverse types of electromagnetic radiations for military use and the denial of these radiations to the enemy for his use are the objectives of electronics warfare. Electronics warfare is divided into two major subdivisions: electronic countermeasures (ECM) and electronic counter-countermeasures (ECCM). It is with aspects of ECM and ECCM that this chapter is largely concerned.

A distinction has also been made between active and passive electronic countermeasures. Active ECM endeavors to prevent or reduce the effectiveness of enemy equipment or tactics which employ, or which are affected by, electromagnetic radiations. This can almost be reduced to one idea—interference with enemy electronic signals. Passive ECM is perhaps not so easily capsulized in definition.

Because passive ECM is often a necessary prerequisite to active ECM, as explained below, the subject is presented first.

PASSIVE COUNTERMEASURES

Passive ECM may include evasion of, search for, interception, direction finding, and signal analysis of enemy electromagnetic radiations that can be put to immediate operational use. A simple example of passive ECM is visual camouflage, effective against television tracking systems (as well as visual or photographic systems) that are used in aircraft, missiles, or satellites. Passive ECM may also involve tactics; for example, a low-level flight to escape radar surveillance, or the use of electromagnetic means to detect missile or gun-laying threats so that immediate evasive action or active ECM may be employed. In Air Force thinking, electronic reconnaissance that can be put to immediate operational use is a further example of a passive countermeasure.

Chiefly, passive ECM means electronic reconnaissance. Its purpose is acquiring information which can be used for such purposes as development of suitable active ECM equipment, determination of tactics, planning of missions, and employment of active electronic countermeasures.

Much electronic reconnaissance is conducted by aircraft known as "ferrets." They are equipped with specialized receiving and recording equipment and direction-finding antennas. Highly skilled crews operate this equipment, and they log and compile the data. The raw data from these missions is consolidated and evaluated on the ground, then compared with other sources of intelligence.

Electronic reconnaissance is also conducted from ground stations which can record and measure electronically such data as ground shock from explosions, ionization paths in upper atmosphere set up by meteor-swift passage of objects, and signals from artificial satellites. Electronic reconnaissance can and will be conducted from satellites by use of radar and television, and by collecting and reporting data on weather or other phenomena with the aid of other electronic devices.

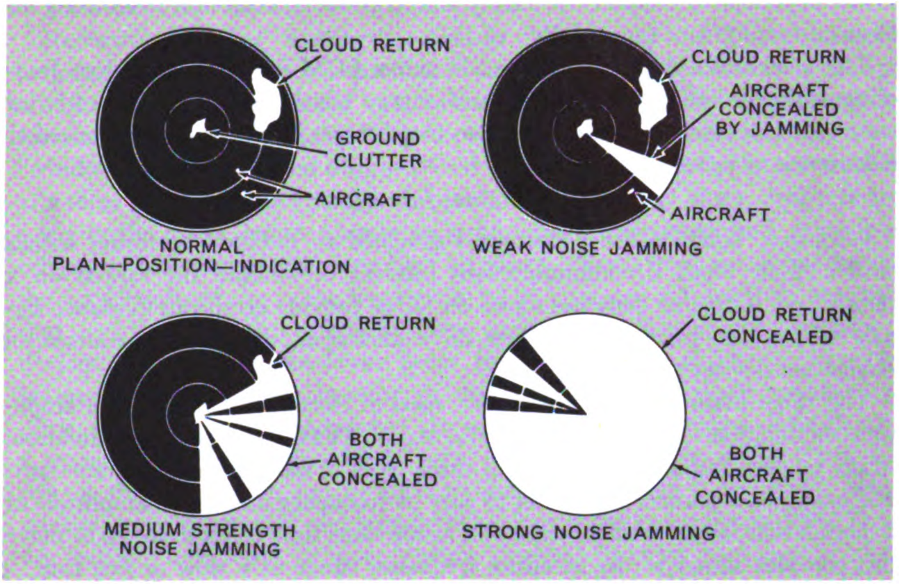


FIGURE 84. Noise jamming as it appears on a radarscope.

The personnel who assemble, analyze, and collate electronically garnered information have had considerable training and experience with such equipment. What is found, analyzed, and reported determines to a large degree the extent of the ECM research and development effort, and eventually the type and quantity of active ECM equipment produced and delivered for use with aerospace weapon systems. Therefore, enemy technical achievements, real or assumed, have a strong influence on the production, development, and modification of ECM equipment.

Quite often the difference between an active and passive countermeasure is not clearly discernible. For example, when a high intensity heat source, such as a flare, is properly dispensed from an aircraft in the vicinity of a heat-seeking guided missile, the missile will home on the flare instead of the dispensing aircraft, and eventually destroy itself. This might be considered a passive countermeasure, since no positive force, such as munitions, was applied to the missile. The dispensed flare might be compared with camouflage designed to distract the flare and thus protect the aircraft. The missile, however, was "interfered with" and rendered ineffective. As a result of this countermeasure, it was also destroyed. The Air Force considers this an active countermeasure under the general heading of electronics warfare.

ACTIVE COUNTERMEASURES

Active ECM includes electronic jamming; deception; and radiation or reradiation, alteration, absorption, or reflection of electromagnetic radiations with

intent to hinder or mislead the enemy and, if possible, keep him from using his electronic equipment successfully.

The principal technique employed in active ECM is that of jamming. Jamming is the radiation or reradiation of energy which makes selected radio or radar transmissions unintelligible. Two major types of jamming devices exist: electronic and reflective.

Electronic Jammers

Electronic jammers are transmitters designed to radiate interfering signals which either block a communications receiver or obscure the targets on a radarscope, distort or deny the sound on radio, provide erroneous guidance signals to missiles, place false targets on radarscopes, or alter the courses on navigation devices (Fig. 84).

The three main types of modulation used in electronic jamming are amplitude modulation (AM), frequency modulation (FM), and sweep modulation. Many modern radar jammers use all three types of modulation simultaneously. For example, a jammer can be set to vary its frequency and signal amplitude at a modulation rate of random noise and at the same time be set to sweep or move this complex signal across its entire frequency range at a slow or fast rate.

Random-noise modulation, either AM or FM, has proved to be the most effective for radar jamming, and it is used extensively for this purpose. Communication jammers, however, use various types of tones; the type of tone used depends on the type of communication device being countered.

Jamming on one or more specific and separate frequencies is called "spot jamming." This method is used when power must be concentrated. In order to economize power, it is desirable that the modulation bandwidth of this type of jamming signal be no wider than that of the victim radio or radar receiver. When a spot jammer is placed on a frequency and is controlled by a receiver, the jamming is said to be responsive. This automatic type of operation is considered the most efficient, since it applies the maximum available jamming power on the right frequencies and at the right time. Power is not wasted, for example, if an aircraft is not illuminated by a radar, nor is power placed on frequencies that are not being utilized by radars. Automatic systems, however, mean more complexity, more weight, more cubage, and higher costs. Therefore, instead of employing spot jamming, it is often better to use less efficient methods, such as barrage jamming.

As the name implies, barrage jamming is designed to cover a broad band of frequencies. Unlike spot jamming, which has a concentrated effect similar to that of a rifle shot, barrage jamming can be compared with the blast from a shotgun. Barrage jamming wastes power on frequencies not occupied by radio or radar signals and, if not used wisely, interferes with friendly operations. Compared with other types of jamming, barrage jamming is more easily detected by passive direction finders or home-on-jamming devices. However, it usually can be produced by a simpler piece of equipment. If it has enough power, it is effective against all types of radars and modulations, and it needs little or no intelligence information.

Reflective Jammers

Reflective jamming is sometimes called "mechanical" or "nonelectronic" jamming, but neither term is particularly appropriate or descriptive. This type of radar jamming is produced by thousands of expendable metallic reflectors of various shapes and sizes called "chaff." This code name replaces the code name "window," which was used during World War II and for many years thereafter as a term which included chaff and rope. The term "chaff" at one time referred solely to the many slender aluminum strips which, when dispensed, cause false echoes on radarscopes that resembled airplanes. These strips, cut to one-half of the wavelength of the radar frequencies to be jammed, act like little antennas that reradiate the radar signals. They were called "tuned," or "resonant," devices. However, at the lower radar frequencies these strips, or "dipoles," became excessively long. Because of this, they were not easily packaged or dispensed from modern high-speed aircraft. In order to overcome this difficulty, a second form of reflector called "rope" is employed. Rope, unlike chaff, is a roll of thin aluminum foil or tape several hundred feet long, which, when released from an aircraft, gives strong reflections at low radar frequencies. These are called "untuned," or nonresonant, devices. Modern packages of these expendable reflectors contain both rope and chaff. Since rope is no longer packaged separately, the term "chaff" now describes the complete bundle or unit of reflective material. The bundles of chaff now used by the Air Force cover the complete usable radar frequency spectrum and respond equally well to radars of all antenna polarizations.

Corner reflectors are another form of radar reflector. The corner reflector generally consists of three mutually perpendicular flat plates joined so that they have a common corner. This simple device tends to focus or reinforce radar energy that strikes it, returning a much stronger echo than that obtained from a flat object of the same total external dimensions. A more effective type of reflector is the Luneberg lens. This as a plastic sphere that has physical properties that permit it to focus incoming radar energy from a wide angle of incidence onto a metal internal surface in such a way that the energy is greatly concentrated as it is reflected back to the radar. The Luneberg lens, however, is much more difficult to construct than a corner reflector, and is thus more expensive.

Corner reflectors are used on the ground as radar targets for airborne bombing systems. They can be used to decoy the bomber away from the real target, provided sufficient numbers of reflectors are employed and the deception is skillfully accomplished. Corner reflectors are made airborne by means of small balloons. As a result, they are widely used for air soundings to determine wind direction and velocity.

Airborne use of corner reflectors as a dispensable or expendable radar reflector is limited because of their size and geometric construction. Corner reflectors, however, can be used to enhance the echoes of vehicles we would like to track better, such as drones and decoys. With the aid of this type of device which enhances echoes, it is possible to make a small aircraft appear like a large

bomber on a radarscope. These decoys can be made small enough so that a bomber can carry several of them. A small force of bombers carrying many decoys and launching them at the proper time can simulate a large force that will saturate the enemy defenses and cause him to commit his defensive weapon systems to little purpose (Fig. 85).

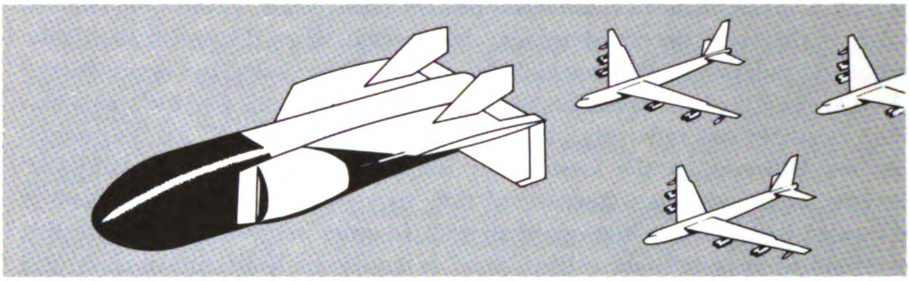


FIGURE 85. The GAM–72 "Quail" diversionary missile. Equipped with countermeasures the missile would be launched by B–52 bombers approaching a target area.

A simpler form of decoy than the radar decoys just described is the infrared flare mentioned earlier in this chapter as a countermeasure against heat-seeking missiles. Infrared countermeasures is a relatively new field of ECM which will assume greater importance with the development and use of missile weapon systems. Infrared detection systems show considerable promise as passive means of detecting and tracking missiles and high-speed aircraft. Such systems will be required for use against the passive infrared terminal-guidance and detection devices of future enemy missile systems.

Jamming Requirements

In determining the requirements for jamming a radio or radar device, one must consider many factors, such as its operating frequency, its location, and its design and purpose. The next questions which concern us are these: What factors determine or affect jamming requirements? How are different radios or radars affected by jamming?

Jamming is used by the Air Force primarily against communications and radar devices. Of the two, the major effort is, and has been, against radars. There are several reasons for this. One is practicality. During World War II, for example, it was more profitable to eavesdrop on the enemy's communications than to jam them. The enemy also found our communications a gold mine of information and generally also refrained from jamming them.

Another reason is that communications jamming generally requires more power (watts per given bandwidth) than does radar jamming. The communications transmitter does not beam energy at the jamming location as a radar transmitter does, but at the site of the communications receiver. This presents several jamming problems: (1) the signal frequency must be found and (2)

since the signal transmission is over a one-way path, the jamming power as heard by the receiver must exceed the power received from the communications transmitter. For example, in jamming ground-to-air fighter communications, the jammer is often farther from the enemy's airborne receiver than the radio transmitter. When a fighter with the receiver is closer to an airborne jammer, the latter must still override powerful ground transmitters installed possibly at many different locations and on many different frequencies. Since airborne equipment is restricted by space, weight, and power limitations, communications jamming is difficult but not impossible. Research has resulted in new techniques and capabilities that, although complex, may provide more communications jamming capability in the future.

Power requirements for radar jamming are not so stringent as those for communications jamming. The radar jammer in an aircraft does not compete with the power of the radar transmitter, but with the power of the aircraft echo as it is picked up by the radar receiver. Several factors control the size of the echo return and the jamming power needed at a given range to override the echo return in radar jamming. The power of the returned echo is affected by the peak power of the radar transmitter, the radar antenna gain, the airplane radar cross section in square feet (a measure of reflectivity), the wave length of the radar, and the range.

The power required for radar jamming is inversely proportional to the square of the range. Thus, the greater the distance between a jamming aircraft and the radar, the less jamming power is required to hide the aircraft echo. (The situation is reversed in normal communications jamming.)

The tube to be used as the heart of any ECM system is selected only after a thorough study is made of the enemy weapon systems that must be countered during a penetration. The density, frequency, diversity, and power of all the radar threats are considered. The techniques that are required to cope with the various threats further dictate the type of tube that will be used. Before a system is finalized and designed, the entire ECM system must be analyzed. If the proposed system is too heavy or too large to fit into the aircraft, if it is so complex that it cannot be maintained, or if it is prohibitively costly, nothing has been accomplished, and the designer must start all over.

Another factor which affects the design of jamming equipment, especially the total power requirements, is the radar cross section of the aircraft that the jammer is trying to protect. The radar cross section is measured in square feet or square meters, and is a measure of the radar reflectivity of an aircraft. For example, an aircraft having an average radar cross section of 100 square feet would reflect the same radar energy as a flat metal plate of the same dimensions.

If the radar cross section of the aircraft to be protected could be reduced, the necessary jamming power could be reduced proportionately. It should be noted that the radar cross section of an aircraft varies continuously, depending on its direction of flight and its elevation and azimuth from the radar station. However, considering any instant in time, model measurements made of aircraft reflectivity show wide differences in the amount of radar cross section for relative bearings of

the aircraft with respect to the radar. Thus, the maximum radar cross section which will be "seen" for the longest time by the radar threat should be used to help determine jammer power requirements. Considerable work has been devoted to developing radar absorbing materials that will reduce radar cross sections ever since World War II, when the Germans first developed such materials for their submarines. The results of these efforts are classified.

Jamming Effects

ECM accomplishes its purpose primarily through confusion and deception. Normally the enemy knows when he is confused, as for example, when many false targets or heavy strobes of noise jamming appear on his scope. Success is attained with deception techniques only when the enemy thinks the false data being received is correct. If the deception device continues to be successful, it will confuse the enemy radar operator in good measure within minutes after its first application. As far as the radar is concerned, the data it is receiving from the jammer are valid or correct.

The primary confusion devices are "noise" jammers. Noise jamming is difficult to counter, since in most cases the jammer transmits electronic noises identical to those which normally exist in a sensitive radar receiver. In fact, a measure of a receiver's efficiency is its signal-to-noise ratio. Since the jammer sends out noise which is similar to, or the same as, the receiver noise, it makes counter-countermeasures quite difficult. If suitable counter-countermeasures were available, they would be inserted into the radar, not so much as an antijamming measure but as a means of improving the signal-to-noise ratio of the receiver and thus increasing the normal detection range of the radar. When the power used for noise jamming reaches a certain point, it can block, or saturate, a receiver. When this happens, no signal of any kind is seen on the scope.

AREA DEFENSE RADARS.—When noise jamming is used against early warning ground-controlled intercept radar or height-finder radar at extreme ranges, even a weak jammer produces a jamming strobe with a beam width at least equal to that of the enemy's. Thus several aircraft flying within this beam width can be protected by one jammer.

Depending on the jamming power and the other factors previously discussed, the jamming strobe gradually widens as the range is increased. Eventually a range is reached where the entire scope is completely jammed, or saturated. This is the ideal situation and depends primarily on how much jamming power can be inserted into the radar sidelobes. In practice, the intensity and effectiveness of jamming is continuously varying. This is especially true when sweep jamming is used. Occasionally, even under excellent conditions of jamming, the radar will get a "free look." Here is where chaff, properly dispensed, can add to the confusion. The combination of jamming and chaff is extremely difficult to counter, since many ECCM's which degrade the effectiveness of jamming do not affect chaff, and vice versa.

Spot jamming can place the necessary power on an enemy's early warning ground-controlled intercept radar and height-finding radar, and it appears to

be the simplest and best solution to the jamming problem. However, the designer of the ECM system must consider the tactical situation. Usually an aircraft penetrating an area defense is under observation by many radars, each employing several beams on different frequencies. These radars are tied together in some form of communication and data-processing network. Jamming just one radar or one beam of a radar is, of course, not sufficient. All must be jammed. One aircraft can seldom carry all the required spot jammers, nor does one operator have enough time to operate and monitor these jammers. This is especially true now that modern radars shift frequency rapidly and often to escape jamming. Designers of ECM systems turn to sweep jammers, responsive spot jammers, or barrage jammers for use against the enemy's early warning ground-controlled intercept and height-finder radars. The advantages and disadvantages of these types of jammers have been discussed previously. The designer can, of course, turn to pulse or deception techniques and employ a false generator to create confusion or saturation of the data-handling network. It is very important, however, that the designer have good knowledge of the radar and ECCM that it employs if this approach is to be effective.

LOCAL DEFENSE RADARS.—The radar defenses around a city or military target consist of short-range (125 to 150 nautical miles) acquisition radars and some form of tracking or track-while-scan radars which are used for gun laying, fire control, target tracking, or missile tracking.

The acquisition radar is similar to a ground-controlled intercept radar. Each of the several missile or air defense batteries about a target area may have its own acquisition radar. The effect of jamming will be the same as that outlined for the area defense radars.

The tracking-type radars have an average range of 50 nautical miles. They employ narrow, or pencil-beam, antenna patterns and are extremely difficult to jam. To improve the accuracy of tracking, some of these radars use four antennas with a single reflector. When a signal is received equally on all four antennas, the centerline of the antenna system is pointing at the aircraft.

The antenna pattern of these tracking radars is so narrow that the ECM receiver of an aircraft will seldom detect these radars unless the aircraft is being tracked. Likewise, jamming being conducted by aircraft not being tracked will have little, if any, effect on the enemy's radar as it tracks another aircraft. Aircraft penetrating a local defense, unlike those going through an area defense, cannot receive mutual jamming support and cover. Each aircraft must carry its own jammer if it is to protect itself against tracking radars. Fortunately, the same noise jammer can be used against both area and local defense radars if the designer can make some provision so that the jamming mode can be selected in flight. When an aircraft penetrates a local defense, its ECM operator is concerned with the one signal that is an immediate threat to his survival. In rare cases, he may be concerned with two to five tracking signals, but the intensity of the signal would advise him which requires immediate attention or jamming. Here, because of the short-range power duel, spot or responsive spot jamming is the method which should be selected.

Deception techniques against tracking radars also offer possibilities. One example of an effective deception technique is "angle-track breaking." In this technique the antenna scan rate is represented as a wave which the deception jammer shifts by 90° or 180° and retransmits. This, in effect, causes the scanning antenna to receive an error voltage large enough to "break track."

Another example is the "range-gate stealer." This jammer detects a tracking signal, amplifies it, and retransmits it with an ever-increasing delay. In essence, the jammer makes it appear to the operator of the enemy's radarscope that the stronger delayed pulses have been reflected from the skin of the aircraft and that the aircraft is at a range which it is not. Eventually the jammer stops transmitting, and the radar finds itself "staring" into empty space. The whole process actually takes but a few seconds. It is repeated over and over again as long as the radar operator helps by trying to reacquire the target.

Chaff dispensed from an aircraft while it was being tracked has, in the past, broken track. The echo from the chaff being greater than that from the aircraft, "breaks lock" in the same manner as the range-gate stealer described above. Again, as the forward velocity of the chaff decreases, the radar operator soon realizes the "aircraft" he is tracking has stopped moving and that something is wrong. Many modern tracking radars can now track the leading edge of the reflected echo. Thus, if the dispensed chaff blooms some distance behind the aircraft, the radar may not even "see" the chaff and will not be affected by it. Modern dispensing methods are being developed, however, which will counteract the effect of tracking the leading edge and overcome this problem.

ELECTRONIC COUNTER-COUNTERMEASURES

A major subdivision of electronic warfare is electronic counter-countermeasures (ECCM). It includes those actions taken to insure that the enemy's use of active ECM does not hinder us from using our own electronic devices effectively. In describing active ECM, mention was made of some ECCM devices and effects. These are numerous. In fact, there are so many of these ECCM, or antijamming, modifications that the list of abbreviations used to describe them is often referred to as "alphabet soup."

Since the purpose of active ECM is to confuse and deceive, the first axioms of ECCM are these: (1) Do not give up. Keep trying to work through the jamming. (2) The best ECCM device is to train the operator periodically in an actual ECM environment. It has been repeatedly proved during training exercises that the enemy's use of ECM becomes less effective as our own operators gain experience and their training is improved. For example, an experienced operator can distinguish chaff from actual targets by noting the fluctuations in the amplitude of the echo and the slow rate of movement.

Technically, many things are possible. Rapid shifting of the radar frequency can be effective against spot jamming. Receivers with large dynamic ranges help reduce the effectiveness of continuous wave or noise jamming. Then, too, there are various methods of delaying echoes and comparing them with false targets

caused by chaff or electronic jammers. These are a few of the many counter-countermeasures that are possible. The techniques to be used should be selected by the operator, since only through experience and training is it possible to know which combination of ECCM fixes will be the most effective at any one time against various combinations of jamming.

When jamming reduces the effectiveness of radars, the operator's experience together with good tactics, operating procedures, and passive equipment help save the day. Fighter aircraft can be used on combat air patrol, and "eyeball interceptions" can be resorted to. When communications are lost, standard operating procedures can be utilized to prescribe frequency changes, broadcast control procedures, and to give similar instructions.

Passive direction finders can be used to locate and track jamming aircraft through triangulation procedures. This technique, of course, is not without some problems also. When several aircraft radiating on many different frequencies are intercepted by passive direction-finding systems at different moments in time, some intricate and automatic method is needed for correlating time and sometimes frequency, if track data are to be accurate. With three or more jamming aircraft, passive direction-finding can become confused by the number of "ghosts," or false bearing intersections. This ghost problem increases with the square of the number of jammers. Narrow antenna patterns at individual passive direction-finding stations, coupled with fast exchange of correlation data between stations, help eliminate the ghosts.

The radar used by missiles and interceptor aircraft, when jammed, can resort to home-on-jamming devices which help solve the elevation and azimuth problem but cannot resolve range. Again, with many jamming aircraft radiating, the home-on-jamming device must have logic and memory circuits to cope with automatic jamming systems, sweep jamming, and the like. These items cause more complications to weapon systems in the form of circuit complexity, added weight, and power or cooling requirements.

Active ECM, with their ability to saturate individual radars and insert false data into the system, cause many problems for SAGE-type systems (Fig. 86).

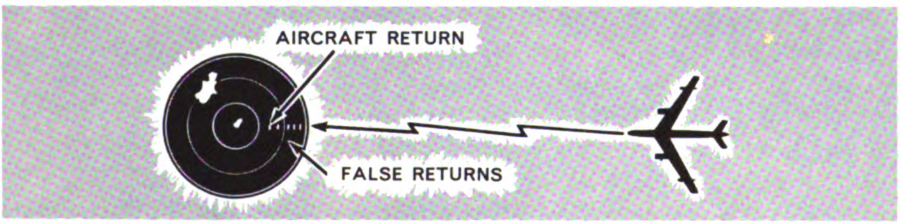


FIGURE 86. False returns modified or generated by an airborne transmitter as they appear on a ground radarscope.

It is apparent that ECM versus ECCM is a continuous battle of wits. If the Air Force is to meet the challenge of electronic warfare, its equipment designers, mission planners, and operating personnel must constantly work to solve the problems outlined in this chapter.

CHAPTER 10

DEFENSIVE OPERATIONS

Any danger of an air attack on North America seemed remote at the end of World War II. Only the United States possessed the atomic bomb and the means to deliver it. But Army Air Forces (AAF) leaders knew that the American atomic monopoly was temporary. They reasoned that even though a future war would undoubtedly begin with an air attack, any such attack would be years away. Since the United States was not an aggressor nation, these leaders assumed that when an attack came, the United States would have to defend itself against

◀ **The Air Force Falcon guided air rocket destroys a high-flying target.**

a surprise attack. Continental air defense therefore would be an important function of the peacetime military establishment, and it would be a job primarily for the AAF.

Discussion of defense during the first months of peace was largely academic, and demobilization was the order of the day. When Army Air Force strength dwindled away, the AAF reorganized along functional lines. A major combat command was the Air Defense Command (ADC). Another, Strategic Air Command (SAC), had first call on the AAF's limited manpower and materiel. ADC, assigned a variety of missions, would have to get along with as little as possible.

One ADC mission was to organize and administer the integrated air defense of continental United States. This meant an early warning radar network and a defensive force to detect, intercept, and destroy attacking bombers. For the job, it had four understrength fighter squadrons and a single training unit equipped with a few World War II radar sets. In fact, the entire AAF did not have the means to fashion an effective air defense. Its relationship with the Army and Navy remained vague, awaiting the outcome of unification and the determination of roles and missions among the services. ADC's role would have to be largely one of training and planning.

Outside the AAF the absence of air defense caused little concern. Most people believed that SAC and the atomic bomb, within limits imposed by the domestic economy, could be counted upon to deter potential aggressors. Other nations would obtain atomic bombs some day, but an air defense system could wait until then.

Air leaders knew better. British experience in World War II had shown that it took time to build an air defense system. And while the United States remained virtually defenseless, the Russians were building copies of the American B–29 good enough to make one-way attacks on the United States with high-explosive bombs. Even though the American atomic monopoly might last for years, the AAF believed that a temporary air defense system was necessary for training as well as defense.

After 1947 the newly independent U.S. Air Force was in a stronger position to push its air defense views and to begin setting up at least a minimal system. Late in 1947, USAF approved a plan—known as Supremacy—for an aircraft control and warning (AC&W) network for the United States and Alaska. The proposed network would consist of 411 radar stations—374 of them in the United States—and would cost nearly $400 million. This was a beginning. In December the Air Force gave ADC's commander formal responsibility for the air defense of the United States in an emergency. In the following March the Joint Chiefs of Staff assigned to the Air Force primary responsibility for continental air defense.

On August 15, 1949, 4 to 6 years ahead of prediction, the U.S.S.R. set off an atomic explosion. Overnight, the United States lost its atomic monopoly cushion. Realization of the true relative weakness of the Nation's defenses spurred rapid actions thereafter.

The plans of 1947 did not begin to bear much fruit until the years 1950–54. By

then, extensive radar and surface-to-air missile systems had become operational, and all-weather interceptors appeared in large numbers. Army, Navy and Air Force units all contributed to the defense picture, and it became necessary to establish an organization to control and coordinate their activities. In 1954, the Continental Air Defense Command (CONAD) came into being as a joint command, with the USAF as the executive agency, to control this farflung defense system. CONAD was directly responsible to the Joint Chiefs of Staff for the air defense of the continental United States. Even at this early date it was increasingly apparent that the defensive problems of the United States and Canada were closely linked. The threat to the American heartland was obviously growing rapidly. The speed, range, and magnitude of Communist offensive power presented CONAD and Canadian defenses with the requirement to expand the size and quality of their respective defense systems.

The inevitable merger of Canadian and United States defenses took place in September 1957. The new international command was called the North American Air Defense Command (NORAD), and its commander in chief was given the mission of defending the United States and Canada from air attack. To do this immense job, the Commander in Chief, North American Air Defense Command (CINCNORAD), was vested with the operational control of all Royal Canadian Air Force (RCAF) and United States service units asisigned to him for air defense purposes. The U.S. CONAD organization remained in existence for purely administrative purposes, and since the CONAD commander was also designated as the NORAD commander, he now undertook both functions. In 1958, Congress passed a law which designated CONAD as one of the unified commands. CINCONAD had now operational command over the U.S. component forces. The ability of CINCNORAD to exercise operational command over the U.S. aerospace defensive forces served to aid CONAD to integrate fully its functions with CINCNORAD. The many ramifications of the 1958 Reorganization Act speeded the elimination of U.S. service duplication, and increased the effectiveness of the defense system.

Two continuing tasks face NORAD: improve the defenses against the manned bomber, and prepare an aerospace defense capability against the ICBM and other potential aerospace weapon systems. These last two involve such things of the future as orbiting vehicles, and weapons associated with space satellites.

American aerospace defense is a joint effort of the United States and Canada. The organization of it has taken its present form and assumed its magnitude in consideration of current and future potentials for destruction of probable enemy aerospace weapons. This involves the capabilities of available defense against future aerospace weapons and the geographical and other natural phenomena which would be encountered by both offensive and defensive forces.

The defense effort of the United States is also a team effort. Air Force, Army, and Navy can receive warning and other air battle information from NORAD; all three provide weapon systems, in combat situations, for direction and control by CINCNORAD. For these reasons, interceptors and missiles used in air defense, regardless of service, are described either in the text or in the appendix.

This chapter will present the reasoning and theory behind aerospace defense; also, a sketch of the organizations of warning and weapons control as they exist today, together with mention of the primary weapons of defense and how they are used.

WHY DEFENSE?

Aerospace defense forces help to deter the enemy. If deterrence fails, they endeavor to prevent enemy strikes from being decisive. These basic objectives of aerospace defense will be examined first.

Deterrent Effects of a Defensive Force

Logically, the offensive power of a nation provides a great deterrence to war. Normally, no nation would launch an attack if certain destruction to itself would follow. Its leaders might hesitate also if they felt that a retaliatory blow would be too costly in terms of casualties and other damage to the heartland, even though they prevailed over a totally destroyed enemy. Just as logically, the defenses of a nation can contribute to deterring a would-be aggressor. Assume that two nations have the offensive capability of destroying the other. Each is poised alertly, so that if one strikes, the other can launch its unimpaired offensive forces. If both blows are struck, who is the victor? The answer is probably that nation with the better defense and the ability to recuperate from a crippling attack.

Thus, substantial results may be had from substantial defenses. As a further illustration of this, defense forces have a real influence on the way an enemy plans and times an attack. If a defensive vacuum exists—that is, if there is no areospace defense—a relatively simple offensive force could fly over an enemy country and destroy targets. The attacker would not need highly developed delivery vehicles. He could use the least costly vehicles to carry even nuclear weapons, and there would be no need to deviate from optimum flight plans.

An effective defense causes a prospective enemy to divert his resources and talents to building quality into his offensive power. If possible, he must build bombers that will fly higher and faster than the defending interceptors. If he cannot produce bombers that will elude interceptors, he must at least increase the speed and altitude at which the bomber can fly. This makes it difficult for interceptors to engage and fire upon the bomber. Or he must concentrate his efforts upon the development of offensive missile systems.

Just as an aerospace defense system forces the enemy to improve the quality of his aircraft and weapons, it also makes him increase the quantity of his offensive power. For example, when attrition from air defense is likely, more aircraft must be launched to get the required number through to their targets. If 200 targets are to be destroyed by bombers, and the air defense system can kill 200 aircraft in an initial attack, then at least 400 bombers must be launched in order to get 1 bomber over each target. If further allowance is made for aircraft grounded for maintenance, lost in training, aborting, and held as necessary reserves, it is likely that an enemy would have to build 600 to 1,000 bombers in order to get 200 over a defended area.

An aerospace defense system, by forcing the enemy to improve the quality and increase the quantity of his offensive forces, compels him to expend time, money, manpower, and overall national effort. In this way a defense system in being buys time and contributes to deterrence.

The Security Functions of Defense

To prevent enemy strikes from being decisive, security for offensive forces and the nation's means and will to fight must be maintained. These together constitute efforts to carry out the second basic objective of aerospace defense.

If the effort to deter is fruitless, the next consideration is to provide for maximum security of offensive forces. Strategic intelligence will already have done a part of this job by monitoring certain national and international indicators, but this method is uncertain. It is also outside the purview of this study. Tactical warning is the greatest single measure for the security of offensive forces. It is provided to NORAD by a farflung network of radars, warning devices, and other means, some of which will be studied later in this chapter. Capable, active defense forces must then be placed between the attacking forces and their targets (Fig. 87).

FIGURE 87. The "Falcon" is an air-to-air guided missile which is designed for use by jet interceptors.

An important consideration in preventing an enemy's strike from being decisive is to preserve the attacked nation's means and will to fight. Important enemy objectives other than the retaliatory forces need to be safeguarded, such as industrial and population centers, vital communications centers, governmental and military control centers, military installations, and people. It would be a hollow victory if military forces survived, while population, along with industry and other national resources, were to be destroyed.

The United States is doing many things to insure survival: the population is being indoctrinated in civil defense; civil warning systems are tied into the NORAD tactical warning net; shelters and evacuation plans have been designed; engineers consider location and vulnerability factors before building new industrial complexes. All of these measures are passive defense actions to reduce or nullify the impact an enemy strike could have on the Nation. These measures supplement, but cannot replace, the active defense actions. The cost of achieving successful defense through passive means only would be astronomical, and would not bring victory. The relocation of entire industries, shelters for millions of people, and the required food, medical, and clothing stores which would have to be safely maintained might well exceed the economic ability of the Nation.

It is a combination of active and passive defense which will insure survival. If two nations have equal offensive power, the nation with the better defenses, both active and passive, may save more of its national military, social, and economic strength and ultimately emerge as the victor.

A peacefully inclined nation, not disposed to strike the first blow, is at a critical defensive disadvantage. It must absorb the first blow, which jeopardizes both offensive and defensive forces. Warning times may be insufficient under the best of circumstances. Such a nation must, of necessity, either maintain relatively superior defenses or accept comparatively greater losses in the initial strike. If it has the means, it will defend. But military planners in the United States must ever keep in mind the need for a balanced force of offense and defense.

THE BASIC ACTIONS OF DEFENSE

In addition to contributing to the deterrence of aggressors, it must be remembered that the mission of the U.S. aerospace defense force, under NORAD, is to defend the continental United States and Canada against aerospace attack. To fulfill this mission, the defense system must be capable of performing certain functions. These functions, referred to as the "four basic actions" of defense, are: (1) detection, (2) identification, (3) interception, and (4) destruction.

The pattern of these four basic actions establishes the general sequence of events which occur in defensive aerospace battle. First, an airborne object must be detected, then its friendly or unfriendly status must be established. If the object is identified as hostile, a defensive weapon must be sent to meet it or intercept its path, and, finally, deliver sufficient force either to neutralize or destroy it (Fig. 88).

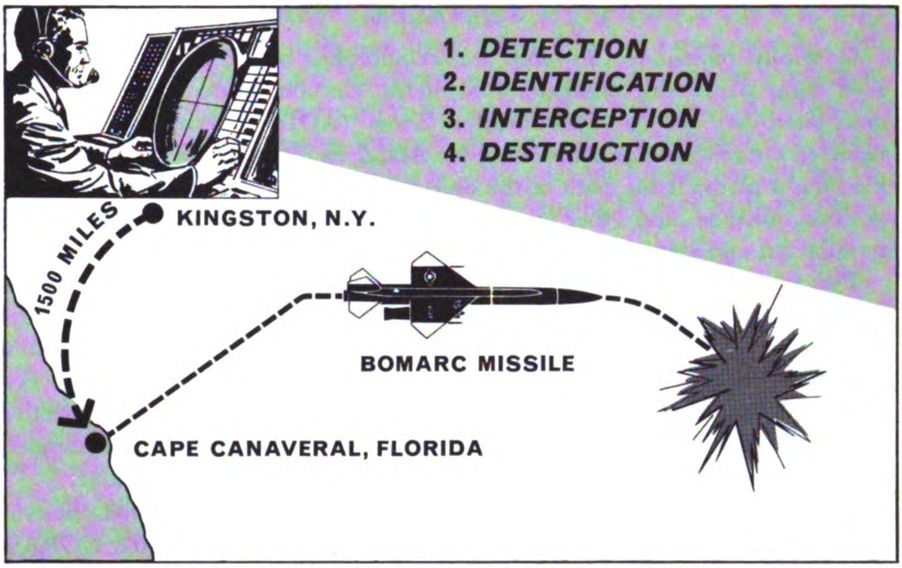


FIGURE 88. The SAGE-Bomarc missile operation includes the "Four Basic Actions" of defense. Distances are not to scale.

The four basic actions are performed by different sections of the aerospace defense "team," but in the required continuity of these steps the components of the system are welded into a cohesive, effective defense. While each action may be examined separately, in actual practice these steps follow in extreme rapidity, and in some instances even simultaneously.

Detection

The responsibility of aerospace defense begins the moment a hostile object becomes airborne. This requires some means of detecting the object as soon as possible. Not so many years ago, a man in a tall tree or atop a mountain discovered the approaching enemy. Today, the infinite reaches of aerospace, plus the supersonic speeds of comparatively small enemy objects, require equipment with far greater discernment than the human eye.

Radar allows man to "see" hundreds of miles and to scan thousands of cubic miles by transmitting pulses of beamed radiofrequency energy into space and recording the echoes reflected from objects in the beam's path. Distance can be determined from the time interval of the "bounce"; direction is determined relative to the position of the transmitter. Radar is restricted to "line of sight" operation, the range of which is influenced by the altitude of the object, due to the curvature of the earth. Ordinary radar, for example, can detect aircraft flying at 20,000 feet 200 miles away, but cannot "see" similar objects at 10,000 feet until they are within 140 miless. Advanced radar systems give more information, and ranges in some systems now set up for the detection of ICBM's allow detection several thousand miles away.

Identification

Generally, most indentifications are accomplished by a comparison of known filed flight plans with radar-detected flights. Certain border areas have been designated Air Defense Identification Zones (ADIZ). When an object is detected approaching or penetrating the ADIZ, its flight path is compared with filed flight plans. If the path of the object fails to correlate with the filed time, position, altitude, and other criteria, a manned interceptor can be dispatched to intercept and identify it.

Two commonly known electronic identification systems are also used, particularly with high-speed military aircraft. The basic principle of each is the same: the suspect object is given a "question" by electronic impulse, and responds with a coded "answer." The older system, Identification, Friend or Foe (IFF), responds only with a "password" impulse. The newer system, Selective Identification Feature (SIF), can also reveal the serial number, flight number, mission or other previously selected data upon detection by search radar.

In addition to these methods, there is, of course, that of educated observation, wherein the tracks of unidentified objects are displayed in the NORAD Combat Operation Center (COC) and subjected to careful scrutiny by trained observers. Any indication of unusual flight activity, concerted maneuvering to avoid or confuse defense systems, or multiple unknown tracks, are grounds for triggering the defense network to action.

Interception

Having been identified as hostile, the object must be encountered by a weapon, either manned or unmanned. In the latter case, interception is concurrent with the next stage, destruction. If a manned interceptor is used, two general types of control are exercised: close (direct) control, wherein a director knows the exact position of both object and interceptor, and issues specific intercept instructions; or remote control, in which the general location of the target is reported to the pilot to aid in contacting the object through his own navigational skill and pilotage.

Weapon directors, on the basis of computed calculations, can direct the interceptor to proceed at desired speed and direction to complete the interception. In the case of late model aircraft with data link equiment, SAGE, to be described later in this chapter, will supply necessary instructions to the interceptor, or even control the autopilot completely, with the human pilot merely monitoring the action. In the completely controlled data link system, even the firing sequence of the interceptor's armament is triggered automatically. Under the Remote Control System, the sequence is similar, but the pilot has operational responsibility for all activity in response to information available to him from the director or his own instruments.

Destruction

In past wars the aerial defense forces were primarily concerned with maximum possible attrition of enemy forces: the destruction of as many enemy

bombers as possible, whether or not their targets were actually hit. Today, with nuclear warheads, the destruction of the attacker takes on a new meaning, for even one warhead delivered to the target will be sufficient. Defense must now strive for 100 percent effectiveness in vital areas. The result has been a tremendous evolution of the defensive instruments from the machineguns and small aerial cannon of World War II to the sophisticated nuclear-tipped missiles of today which could conceivably destroy an entire enemy air fleet with one blast.

PREPARING FOR AEROSPACE DEFENSE

In order to fulfill the four basic actions of aerospace defense just reviewed—detection, identification, interception, and destruction—a modern aerospace defense system must follow a continuous program of planning, building, and improving the system (Fig. 89). Although these three activities are closely interwoven, it is possible to isolate and examine some of the basic concepts of each.

Defense planning rests upon the consideration of two basic factors: the enemy threat and the targets to be defended. The enemy threat is the yardstick against which the ultimate effectiveness of the system must be measured. An enemy's threat is actually a composite of his capability, plus his intentions in respect to a defending nation. To the best of a defender's ability, he assesses a threat in terms

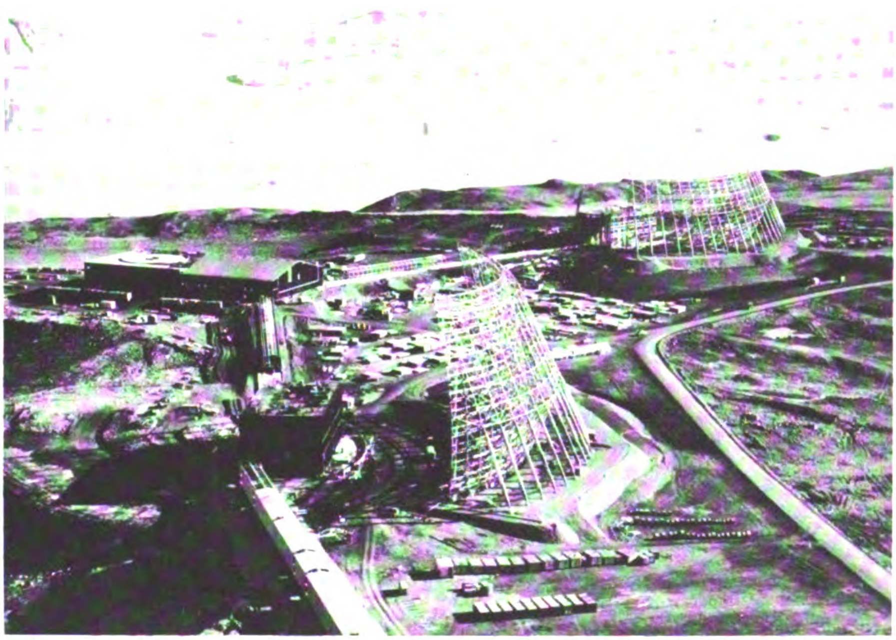


FIGURE 89. A view of the 400 ft. by 160 ft. antennas under construction at an Air Force BMEWS installation.

of aircraft, missiles, bases, and the remainder of an enemy's inventory, together with the speed, range, altitude capability, and other component features of enemy weapon systems. An attempt must be made to project trends in enemy capabilities. What will they be a year or two hence? What are his plans beyond this time?

An enemy's intentions may be deceptively simple. But imponderables of international intrigue may make an assessment of intentions exceedingly complex or impossible. While certain international "indicators" may be observed and analyzed, defense in our time is probably predicated on the assumption that the Nation's security depends upon preparation against attack by nations with the worst of intentions.

The remainder of this section will present the thinking of modern aerospace defense strategists, and summarize the main applications of the principles, as now existing in NORAD.

Choosing Targets To Defend

What targets are likely to be selected by an aggressor? Almost surely these are the targets a defender would most want to protect, but this idea must be modified by several considerations. One of these is whether or not an enemy has the capability of reaching, and destroying, a highest priority target. While any point on earth is today considered vulnerable, a pinpointed high-priority target may be well protected in a "hard" site, and well defended. An offensive thrust may have to pass up such a target as too uncertain of destruction, or possibly involve too costly an effort, and use available offensive weapons on targets of lesser importance.

Individual pinpointed targets may be ignored by an enemy for another reason; it may be a part of a "target system." Targets need not be closely grouped in a geographical sense to constitute a target system, but their similar or related functions might seriously handicap the entire target system if only one or several were destroyed. An example of a target system may be the whole train of production for a jet engine; if turbine blade production facilities are destroyed, it matters little that the plant for assembling jet engines is located deep within a mountain tunnel.

Target systems today are usually larger in scope than the simple; almost obsolete example above. With the power of modern nuclear weapons such that 50 weapons, falling on 50 of the most important metropolitan areas of the United States, would bring under attack half its population and three-quarters of its industry, target systems are now described in terms of offensive force, population, and heavy industrial production centers.

High on the priority list of NORAD-defended targets are the offensive strike forces and the major metropolitan areas of the United States and Canada. Areas to be defended are accorded relative priorities for defense. These objectives are then translated into requirements for the defense of the areas. This is a part of the strategic planning of NORAD, prepared jointly by the United States and Canada.

Balanced Defense and Defense in Depth

POINT AND AREA DEFENSES.—In general, "point" defense concentrates on specified geographical areas, cities, and vital installations. "Area" defense involves the concept of locating defense units to intercept enemy attacks remote from, and without reference to, individual vital installations, complexes, or other target areas.

Today, NORAD is constructed on an area defense concept, but employs both point and area weapons as complementary components of a "family of weapons" operating in conjunction within the defended area. ("Family of weapons" will be explained later.) Although there is general agreement of the need for the entire system to be operated on the area concept, the point and area weapon systems used have certain advantages and disadvantages.

Point defense weapons are usually typified by a high rate of fire, usually using nonrecoverable surface-to-air missiles of the Nike family variety. Each complex is autonomous and can fight on an independent basis if necessary, although the firing units normally receive information and control from the SAGE control centers, to be described later. The range of fire of a unit is limited—about 75 miles with a Nike-Hercules, which can attack a target moving at more than mach 2.5 and reach altitudes well over 100,000 feet. Point defense weapons have both high-explosive and nuclear capability.

Area defense weapons operate at comparatively greater ranges. Today, with the exception of Bomarc, they are manned weapons. Their ranges allow them to reach out and disrupt enemy attack plans, cope with decoys and electronic countermeasures, and gain additional time for combat. Ability to extend range toward the launching area, and to destroy nuclear-carrying enemy vehicles over remote areas, is important in protecting populations, and because carriers of air-to-surface missiles (ASM's) can be destroyed before they have an opportunity to release their smaller, warheaded weapons. Also, nuclear weapons can be used freely in their destruction. Area defense weapons permit true defense in depth.

Balanced defense refers to facing the up-to-the-minute realities of offensive capabilities of possible enemies, and using available resources with utmost efficiency for defense. Several years ago, for example, almost the only threat to North America could be countered by a line of warning radars and available defensive weapons facing northward across the arctic wastes. Today balanced defense must encompass 360°. This results because ranges of offensive weapons have increased so that they may "home-in" from any direction. Also, weapon development now gives an enemy the capability of launching attack from the sea, either from air or submarine bases. Nonetheless, probable direction or paths of attack cannot be ruled out even today. ICBM's probably would approach from polar areas, and this probability, plus the probability that the bulk of a massive attack with other types of weapons would still approach from the north, is reflected in the emphasis given to the concentration of detection and defensive weapons in the north. The improvement of ICBM's has resulted in enlarging the defense area in still another direction—up. The BMEWS network of detection

radars is designed to counter this threat. Some aspects of BMEWS will be studied elsewhere in this work.

Several years from now this vertical expansion of the defensive area may be ballooned in area to indeterminate magnitude by space vehicles fitted for offensive attack.

The defense that has been described so far in this section in effect resembles a huge hollow shell. Regardless of how desirable it might be to intercept enemy offense forces along the perimeters, total interception is impossible. "Defense in depth" relates to the capability of defending a comprehensive area defense by bringing firepower to bear continuously at any time and point desired, from launch of weapon to target. This ideal is not a likely prospect for some time, but certain factors may be used to determine how much defense in depth should be built into the defense system at the present time.

Hundreds of variables might be considered in planning adequate defense in depth. These variables range from the emotions, training, and intelligence of personnel to the reliability factors of giant, complex digital computers which must be programed, moreover, with intelligent and well-evaluated data. Also, the actions of the enemy have a primary influence on the solution of some of these problems, and these will not remain stable.

COMBAT TIME, SPEED, AND ENEMY WEAPONS.—These three factors of area defense in depth have primacy in giving a better understanding of the needs of defense in depth.

Combat time may be defined as "the time you must spend with the enemy to destroy him." Combat time depends upon the rate of interception of the defense system, and the required interceptions to destroy an enemy force.

The rate of interception of the defense system—attempts to kill an enemy—cannot readily be measured. For example, a machinegun shooting 1,200 rounds per minute could be regarded as trying 1,200 times in a minute. This is an impractical and oversimplified idea. However, it is practical when reckoning needs for defense in depth to consider the kill capabilities of a portion of an entire system of defense. Theoretically, this segment of defense can, let us say, make an average of 40 lethal passes (interceptions) per minute, using the weapons with which it is equipped, such as missiles of various types. Theoretical perfection, it must be estimated, will never be achieved. The rate of interception is now assumed to be reduced to 28 interceptions per minute by such quality factors as lack of training of personnel, malfunctioning radars, faulty communication, etc. These and a host of other inefficiencies may always be expected to be present and anticipated. What, also, are the efficiencies of the weapons available? Is their reaction time fast enough? Can they attain sufficient speed, range, or altitude in time to do the job? It may be expected that the reliability of their guidance systems and warheads will be less than 100 percent. It is probable that all of these and many other inefficiencies of the weapons themselves can also be assigned a mathematical certainty of happening. Together, it can be reckoned, this segment of the defense system will now have an average estimated rate of interception of 20 per minute.

The enemy side of the picture must now be examined to determine as closely as possible the interceptions required to destroy a probable force, and to allow the defenses to determine also "combat time" required for accomplishing this.

It must be considered that the enemy can choose the time, place, and method of striking. He can vary the size of his force, and use a wide range of tactics, variable altitudes, confusing formations, decoys, and electronic countermeasures, among other procedures of choice. This illustrates one virtue of a strong, well-equipped defense system; the enemy is caused to do these things, thus pouring much of his resources into his every effort. The above illustration is also simplified to the point of absurdity, but it allows some inkling of the complexities of reckoning combat time.

The speed of the enemy force implies a moving air battle, and the distance covered while expending combat time is known as the combat distance. Insofar as the defenses are concerned, this is an oblique way of restating defense in depth. The formula for finding combat distance is: combat time required $\times$ enemy speed = combat distance.

The third element in planning for defense in depth concerns enemy weapons. In dealing with enemy bombers which drop conventional free-falling "gravity bombs," it can be determined that the bomb will travel a considerable forward distance during its fall. A mach 0.85 (490 knots) enemy bomber, flying at 50,000 feet, would drop its bomb about ten nautical miles from target. A defense

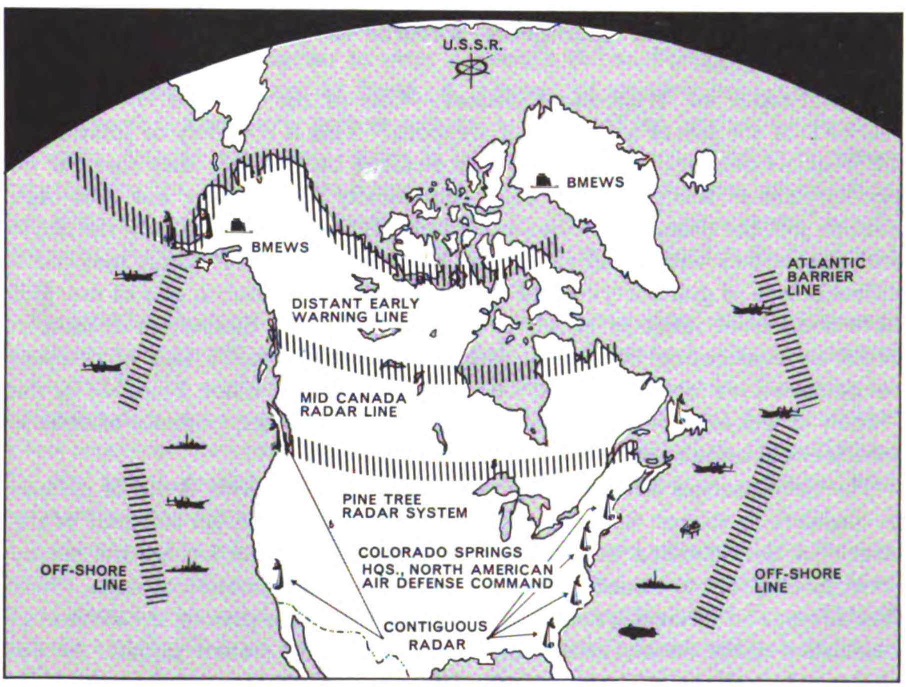


FIGURE 90. A conception of the NORAD continental defense system.

system commander, realizing that it is highly improbable that a bomb could be destroyed while falling, draws an imaginary circle with a ten-mile radius around the center of each projected target impact point, and uses this as a reference line. The line of the circle is known as the bomb release line (BRL). It represents the last point where an enemy must be destroyed if the target is to be saved. Improvement of offensive weapons makes this illustration almost obsolete; BRL has now been moved out to equal the distance of the range of air-to-surface missiles of the Hound Dog type. This may now be as much as 100 nautical miles; later it may extend to 500–1,000 miles as improved air-to-surface missiles become operational.

Nuclear weapon fallout may cover hundreds or thousands of square miles with radiation sufficiently intense to produce death or incapacitation. The advent of this weapon complicates still further the problems of planning defense in depth.

All the foregoing factors, with others unmentioned, combine in the calculations which choose radar sites, weapon bases, and warning lines. They give guidelines for building the entire defense system (Fig. 90). NORAD planners must reevaluate them constantly.

The advent of the ICBM does not appreciably change the defense in depth problem; it only changes the limits of time, speed, and distance. Defensive counterweapons to ICBM's may be postulated: infrared satellites for early warning radars; tracking and readout stations to replace search radar and control centers; acquisition devices, guidance equipment, and new weapons to complement current interceptors; airborne weapon control systems; and air-to-air missiles.

THE FAMILY OF WEAPONS CONCEPT.—One of the concepts embodied in NORAD is the use of a "family of weapons." This is a variety or mixture of different weapon systems. Such use is dictated by the fact that there is no perfect defense weapon which can economically do both the low and high altitude job, the distant and close-in fighting, and defend against both the single and mass attack with equal capability. Each weapon in the family may use a different type of guidance, control system, armament, warhead, rate of fire, and have a different range of effectiveness. This permits a qualitative defense in depth by confronting the enemy with the almost impossible task of carrying countermeasures for all of them. The tactical versatility made available by the "family of weapons" is most apparent in three areas: range, guidance of defense vehicles, and armament.

The varied ranges offered by the different weapons provide depth of defense in considerable degree. Selective deployment permits maximum coverage of the targets in the defended area. Longer ranged weapons can engage the enemy early, forcing him to commit himself to tactics such as formation changes, decoy launchings, and electronic countermeasures. This in turn permits the defense to establish possible enemy intentions, final routes, and chosen targets. As the enemy moves closer to the target area, different defense weapons are brought to bear in a pattern of increasing firepower.

A family of defense weapons will have weapon systems with varied guidance systems which the offensive enemy must counter. If the enemy attempts to jam ground search radars, airborne radars can do the job. If the enemy tries to confuse a radar-guided missile, an infrared missile may seek him out. If he arms his tail position heavily for defense against attack, the tactic used by defense may be to hit him from the front quarter. When he builds up power to jam normal voice communications, commercial radio facilities with tremendous power output can be used. Counter-countermeasures are also built into some defense weapons' guidance systems.

The variety of armament offers another imposing obstacle to the offensive enemy. If he attempts to use formation tactics to better provide defense against manned interceptors, he may lose the entire formation to a nuclear rocket. If he overflies an area defended with surface-to-air missiles, the lethal rate of fire as well as nuclear capability must be reckoned with. The varying ranges, rates of fire, and radii of weapon effects all combine to give the defense a selective lethality of firepower. Maximum kill rates are possible, yet economy of effort is not sacrificed.

Centralized Control.—The four basic actions of defense—detection, identification, interception, and destruction—could theoretically be performed by one man, flying a manned interceptor. This would constitute centralized control; however, more sophisticated centralized control is a part of NORAD's organization. This will be studied later under the subsection "Warning and Control Systems."

Forces in Being and Future Defense Weapons.—In planning for defense it is not enough to program to meet a present threat. Forces in being must counter offensive weapons in being. A moment of decisive importance may come a week before a new defense weapon is rolled off the production line. An aerospace defense system must strive to keep ahead of enemy offensive improvements. Weapon development, never at a standstill, progresses typically in two fashions: by gradual improvement, and by dramatic "new weapon" breakthroughs. Both must be anticipated if defense is to be effective in its several roles.

Essentially, there are three major areas in which a modern defense system is constantly improved: capacity, control quality, and weapons. Capacity means ability to handle a problem within definable areas. For example, if a radar installation does not cover the area below 1,000 feet or above 60,000 feet, these levels represent the upper and lower limits of the capacity of that installation. To cite an illustration already given, interception capacity is definable, and constantly being improved.

Control quality refers to the efficiency of the parts and personnel of a defense system. Already reviewed have been the measured and estimated efficiencies of these components used when evaluating the interception rate of a balanced defense system. Greater control quality than originally estimated is a desirable achievement for several reasons. It will provide a safe margin so that anticipated interceptions will not fall below a minimum programed level. Also, greater

control quality alone, in some areas, will increase the total interception capability of a system. For example, better methods of identifying friend from foe, faster communication, and automatic devices for navigation, armament preparation, and even firing will all save time, and often add to combat time, all without altering other components of the system. The quality of control perhaps becomes most important when operating in a severe electronic countermeasure environment.

The importance of weapons improvement is perhaps self-evident. Nevertheless it must be considered that the marriage of the various weapons with ground environment and control has produced the need for precise methods and tactics when employing these weapons. The ground-air defense "team" must be constantly trained for maximum effectiveness because weapons improvements never cease.

Continuous evaluation of the defense system must be maintained. A modern defense system undergoes constant changes with contributions to it by civilian industry, governmental agencies, and other military forces. Reevaluation of all facets of aerospace defense is a never-ending task.

DEFENSIVE WEAPON SYSTEMS

An aerospace defense weapon system usually includes an aerospace vehicle as the major operational element. With all the related equipment, materials, personnel, skills, and techniques to operate this vehicle, the entire system becomes a self-sufficient unit of striking power in its intended operational environment. Two major categories of weapon systems are assigned to NORAD: all-weather interceptors (which include the IM-99 Bomarc "unmanned" interceptor) and surface-to-air missile systems.

In addition to the presently controlled NORAD system with its Canadian components, in a national emergency NORAD would assume command of a number of augmentation forces from the Army, Air National Guard, and Reserves. These forces include all-weather interceptors, dayfighter aircraft, and surface-to-air missile units, as well as other weapon systems which could be used for interception work.

All-Weather Interceptors

Many persons, including a number of military personnel, erroneously consider "fighter" and "interceptor" aircraft to be identical. This has been the basis for many misunderstandings. Adding to the confusion, certain missiles, already operational or planned, such as the Bomarc, are sometimes designated as "unmanned interceptors," and sometimes "guided missiles." Also, anti-ICBM missiles could be designated interceptors or perhaps surface-to-air missiles.

The all-weather interceptor has been a logical development from the fighter aircraft, and even today each one is capable of fulfilling a portion of the other's mission. But the similarity ends here. The fighter is equipped for operations requiring air-to-air combat against other fighters, for clear-air use in mass operations, or for highly specialized activities such as interdiction, battlefield sup-

port, and reconnaissance. The fighter aircraft is characteristically small, highly maneuverable, and fast.

Interceptors—manned versions of which, such as the F–89, F–101, and F–102, are still called "fighter-interceptors"—are accepted today as precision machines designed to operate under any weather conditions for the express purpose of intercepting and destroying enemy airborne objects. They have a high rate of climb, are not necessarily highly maneuverable, but carry the equipment required to seek, find, and destroy an enemy. Where perhaps day fighters could be compared to a destroyer vessel or torpedo boat, the modern all-weather interceptor is a "cruiser of the skies"—capable of searching out and destroying the largest airborne "battleship" in a single punch (Fig. 91). In their roles as air-to-air combat weapons against enemy aircraft, they have capabilities that fighters do not have.

Development of Capability.—After World War II serious thought was given to adoption of an entirely new concept for defense. There were a number of good reasons for a new concept. Jet bombers were on the drawing boards which represented greatly increased speeds for offensive forces. This meant very little speed advantage—or perhaps none—for the fighter. At most, the fighter would be able to make one firing pass and then he would be unable to reattack because of the high speed of the bomber. Also, the newer bombers could carry very heavy armament and would be capable of defending themselves against fighter aircraft—particularly against strikes in the tail section. The offense could now bomb in any type of weather and at any time of day or night. Further, the number of modern bombers available to a nation could cause complex saturation problems to a defense unless a positive means of controlling the defensive air action were designed. Finally, the advent of high-yield weapons demanded that defenses provide maximum protection from enemy attacks and not function merely to cause enemy attrition.

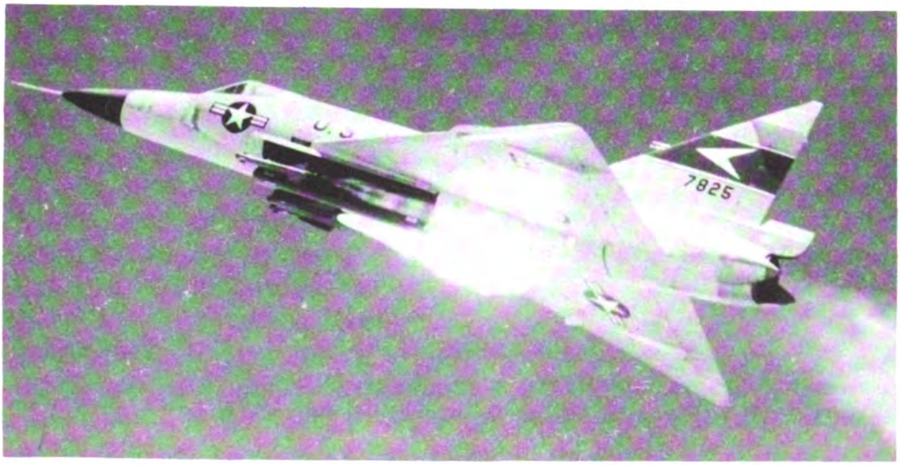


Figure 91. An F–102 interceptor fires its rockets during a training mission.

Study of the growing offensive capability led to the decision that future defensive fighter-weapon systems must have several characteristics that previous fighters did not have. These new weapons must be able to—

1. Operate in an environment which would allow early detection and continuous tracking of an enemy force.
2. Operate under positive ground control to assure flexibility, concentration of firepower, and economy of effort.
3. Climb rapidly to a bomber's altitude and be able to attack it successfully from any angle of approach—tail, side, or head-on.
4. Destroy the bomber with a single firing pass; also, if possible, to attack and destroy a bomber which might have speed superiority.
5. Operate under all conditions of weather or darkness with equal effect.

These characteristics called for a radically new weapon system. The new system was to be the all-weather fighter-interceptor. The improvements in both ground radar and airborne radar equipment after World War II provided several advanced "night fighters" which, although an improvement over the early types, were still limited in many respects. Not until 1952 did the first true all-weather interceptors begin to appear. These first interceptors were the F–94C, F–89D, and F–86D aircraft. These had the capability to take off, climb to the bomber's

FIGURE 92. In the SAGE system an electronic gun is used to interpret specks appearing on target scope.

altitude, find and attack the bomber, return to base and let down to the point of landing—all solely by instruments. Only the initial takeoff and final landing phases had to be conducted by visual reference outside the cockpit.

The introduction of the F-102A, F-101B, and the F-106A interceptors, combined with better radar and air-to-air missiles, has resulted in a major step forward in contemporary air defense. These current interceptors represent an advantage of interceptor speeds over bomber speeds by a considerable margin—in some cases interceptors are twice as fast as the bombers they would oppose. This is a condition that may be expected to change again. Equalization of bomber-interceptor speeds and altitude capabilities will occur, and the seesaw of offense and defense here, as in all aspects of warfare, will continue.

Today, enemy bombers face the latest in nuclear-tipped missiles. Also, the parallel improvements in airborne radar and associated ground-air control equipment, including the SAGE system, has allowed a tremendous increase in tactical flexibility. The combination of added speed, range, and firepower of the new interceptors, coupled with this increased tactical flexibility, has resulted in a very high degree of effectiveness against the subsonic air-breathing enemy aerospace vehicle threat.

ARMAMENT.—The evolution of the armament carried by all-weather interceptors has clearly indicated the determination to stop the air-breathing vehicle threat. Progress from the machineguns and cannons of World War II to today's nuclear air-to-air missiles vividly illustrates the strides that have been made. Although the cost per shot has risen greatly, the kill effectiveness of modern missiles has increased tremendously. Where before, a fighter might make many attacks against a single bomber and finally leave the combat area with only a damaged bomber to show for his efforts, today a single interceptor, with a split-second missile launch, can destroy an entire formation of enemy jet bombers.

The advent of more modern interceptors stimulated development of new armament. These include the guided aircraft rocket missiles (GAR). These new missiles rely chiefly upon radar and infrared (heat seeking) guidance devices. One, the radar semiactive seeker missile, operates by the incorporation of a small radar antenna "eye" in the nose of the missile which receives radar energy bounced off the target aircraft by the interceptor's radar set. The missile's guidance system then steers the launched missile toward this point of reflected radar energy, changing course as necessary. This means of missile navigation is known as "proportional navigation," since the missile can turn in the direction of angle change (as the target maneuvers) and at a time rate proportional to the angle change rate. The infrared-guided missile operates in the same manner, except that the radar antenna in the nose of the missile is replaced by an infrared sensing "eye" which homes on the enemy aircraft's hot engines or jet exhaust.

The advantages of the GAR missiles quickly became evident. They can be launched miles away from the enemy target; they can follow maneuvering targets easily through the use of proportional navigation; they can climb above the absolute altitude of the interceptor and so extend the effective weapon ceiling of many interceptors; they can carry larger warheads, even nuclear war-

heads; their use minimizes the need for exact positioning by the launch vehicle—the interceptor no longer has to be pointed directly at the target; and finally, they represent a new plateau of armament which gives promise of even greater growth potential. Cost per missile is high, but mass production is reducing costs. Modifications have greatly increased reliability. The GAR missiles are today the mainstay of manned interceptor armament.

An air-to-air, unguided, and nuclear armed rocket, the MB–1 Genie, was introduced into the inventory in January 1957. This rocket is designed to knock an entire formation out of the air. Overnight, probability of a kill by a manned interceptor armed with the MB–1 became almost certainty. More recent developments in this area have produced a guided aircraft rocket with nuclear capability. This is the GAR–11 Falcon, which is capable of radar guidance after launching from the interceptor aircraft. The majority of NORAD interceptors now have nuclear capability.

In addition to the Genie and Falcon missiles, the NORAD arsenal contains the Mighty Mouse, a folding fin aerial rocket (FFAR). Further data on the Mighty Mouse and on various models of the Genie and Falcon may be found in appendix B. Here also are described the two Bomarc unmanned interceptor models.

Appendix A lists and describes various current NORAD interceptors under the title "Principal Operational Aircraft." Appendix A includes also Air National Guard interceptors, which would fall under control of NORAD in a national emergency.

BOMARC UNMANNED INTERCEPTOR.—The first unmanned interceptor unit, the IM–99A Bomarc, became operational in 1959. This is a large, surface-to-air missile, armed with either a conventional or atomic warhead, capable of reaching out several hundred miles to destroy an enemy aircraft. The Bomarc is a supersonic, surface-to-air missile—called an "unmanned interceptor" because it uses aerodynamic principles for flight involving wings and control surfaces (Fig. 93). It is designed as an area defense weapon system. Bomarc is described in appendix B.

Surface-to-Air Missiles

The U.S. Army Air Defense Command (USARADCOM) is the Army component of the North American Air Defense Command and the Continental Air Defense Command. Operationally, its weapons and functions would come under NORAD control in actions against an enemy.

Air Defense artillery units assigned to USARADCOM consist of surface-to-air missile units of the Nike, Hawk, and Talos families. While these Army missile systems are often referred to as "point defense" weapons, they can and do defend vital areas of substantial size. Urban areas and complexes defended by these missiles in many instances cover thousands of square miles. Therefore, the term "local" defense rather than "point" defense is considered more descriptive of the Army's air defense systems. "Local" defense also implies the capability of fighting air defense battles on an independent basis if necessary,

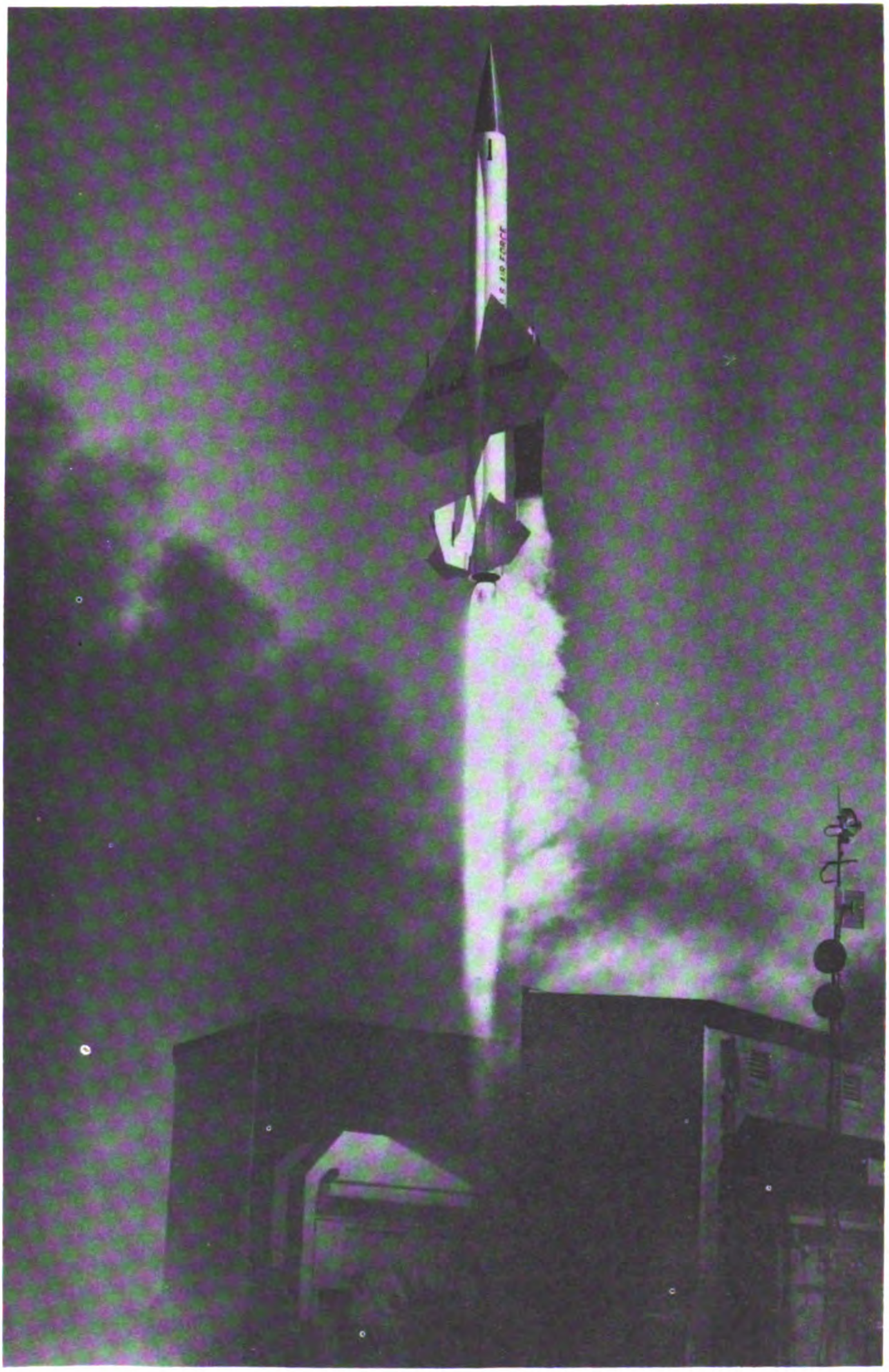


FIGURE 93. Closeup of a Bomarc missile launch.

since each surface-to-air missile battery is self-contained and capable of acquiring, tracking, and destroying a target.

The basic combat unit is the missile battery, located well away from the defended locality to permit early engagement and destruction of the enemy. Batteries overlap in fields of fire, thus providing mutual support. Batteries are linked with the entire defense through a central coordinating center, manually through the Army Air Defense Command Post (AADCP) or electronically through the Missile Master facility.

Functionally, local defense weapons complement area defense weapons in a system in consonance with the area defense in depth concept. They are a part of the overall "family of weapons" deployment of NORAD, and under the operational control of CINCNORAD.

Army National Guard air defense artillery units, upon accepting active missile sites in any national emergency, would become integral parts of the defense system. These units no longer contain antiaircraft cannon.

FIGURE 94. A covey of prime air defense weapons in the North American Air Defense Command. The Convair F–106A Delta Dart, front and center, stands poised with Genie air-to-air atomic missile and a Hughes Super Falcon at its elbow. In the background, left, is the sister ship to this mach 2 fighter, the F–102 Delta Dagger. The Army's contribution, the Nike-Hercules surface-to-air atomic tipped missile holds down the slot position. Lockheed's F–104 Starfighter rounds out the deadly quartet. All of these modern air defense weapons are on duty with units of NORAD.

In addition to the Nike missiles of the Army, the Hawk air defense missile system is designed to cope with high-speed, low-altitude targets. Hawk's continuous radars and homing all the way guidance are not affected by ground clutter. The Hawk system is mobile and specifically designed to search out and destroy hostile aircraft or cruise-type missiles from treetop level to medium altitudes, and can destroy targets flying at twice the speed of sound. Hawk equipment can be airlifted by fixed or rotary wing aircraft. The Hawk and Nike missiles are described in appendix B.

WARNING AND CONTROL SYSTEMS

Warning and control are sequences, but inextricably bound together in purpose and in the organization and equipment necessary to accomplish these functions. The meaning of warning is self-evident; control needs explanation. It involves centralizing intelligence where needed, evaluation of data, suggestions concerning actions to be taken, human judgment, and finally the machinery and methods for activating the organizations and weapons of aerospace defense. Even though this section is divided into two parts, it is necessary to keep in mind that a sharp distinction cannot be made between the two.

Autonomous warning and control has been developed to an amazing degree with the aid of electronic sensing devices, extremely rapid communication facilities, and digital computers and other electronic equipment. Even more complex automatic equipment is constantly added to the system, and new systems are always in evolution. Despite this picture of a "pushbutton" aerospace defense, several things must not be forgotten. One is that the day of the manned interceptor is not past. Perhaps even more important is the sober fact that final judgments and orders must be reserved for commanders. When the time comes to defend North America, only the highest authority must give the word to fire.

Warning Networks

The first basic action of defense, detection, is dependent upon a series of radar "lines" in depth. Although these lines may be examined as units, they are integral parts of a cohesive, mutually supporting system, or network, which supplies warning and control information to the Combat Operations Center (COC) of NORAD. The system was not installed as a unit, but was evolved over a number of years, becoming progressively more extensive and more sophisticated. The present system consists primarily of the Pine Tree Line, the Mid-Canada Line, the Distant Early Warning (DEW) Line, and the Ballistic Missile Early Warning System (BMEWS). Research continues in efforts to further improve and extend network range and capabilities.

Radar Warning Lines.—The Pinetree radar warning line, established first, is an east-west line of radar stations along both sides of the United States-Canadian border.

The second line, the Mid-Canada, is in operation along approximately the 55th parallel, beyond the normal zone of settlement. The Mid-Canada Line consists of a series of unmanned doppler detection stations extending westward

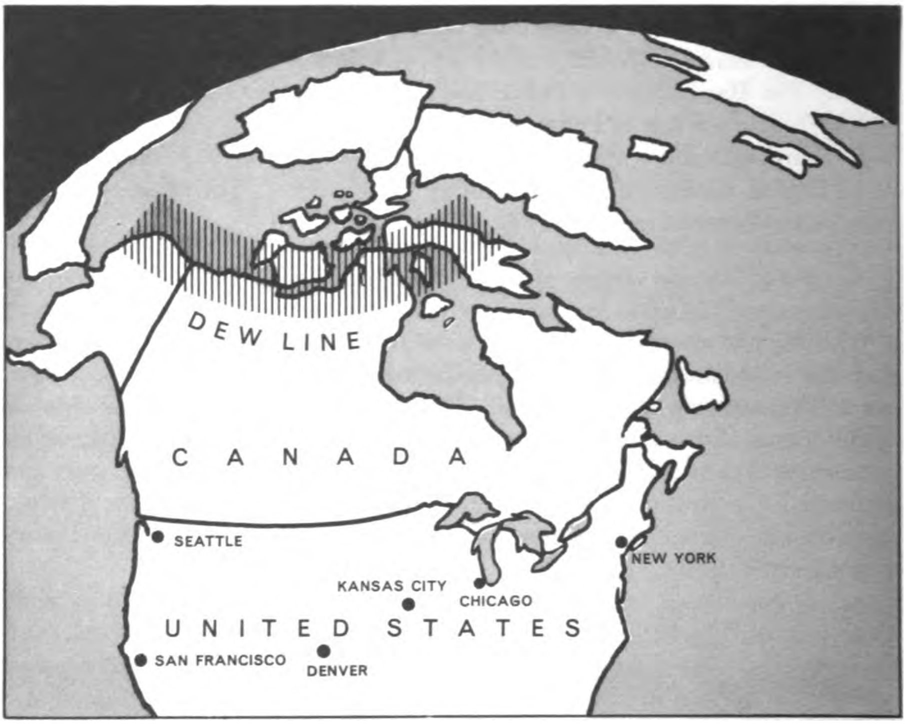


FIGURE 95. Broken line shows approximate location of the Distant Early Warning (DEW) line.

from Labrador. The Doppler effect, a well-known physical phenomenon, is used here to determine speeds of objects under surveillance and aid in determining direction. The Mid-Canada Line was constructed and is operated by Canadian forces, but is completely integrated into the overall warning system.

Farther north, running across the northern rim of Alaska and the Canadian Arctic is the Distant Early Warning (DEW) Line, with over 60 warning stations stretching along 3,000 miles of arctic wasteland (Fig. 95).

In addition to the well-known lines mentioned, there are flanking and contiguous capabilities. The flanking capabilities exist in U.S. Navy radar-equipped destroyer escorts and WV–2 Super Constellation aircraft patrolling the areas extending from the Aleutian Islands to the mid-Pacific, and from Newfoundland to the mid-Atlantic. The contiguous coverage is extended along the perimeter of the United States by U.S. Navy picket ships and ZPG–2W blimps and USAF RC–121 radar aircraft. In addition, the U.S. Air Force operates offshore radar platforms (called "Texas Towers" because of their resemblance to certain types of offshore oil derricks) in the Atlantic. Also contributing to the contiguous radar net are radar stations all over the United States.

BMEWS.—The latest addition to the warning network is the Ballistic Missile

Early Warning System (BMEWS). The primary purpose of BMEWS is to provide distant early warning of missile attack. Begun in 1958, BMEWS consists of three huge radar stations located at Thule, Greenland; Clear, Alaska; and Flyingdales Moors, United Kingdom. Each station is equipped with a gigantic radar antenna about the size of a football field, capable of detecting a missile over 2,500 miles away (Fig. 96). Data flashed to the NORAD COC can there be electronically evaluated and a resultant plotting of launch and impact areas indicated on a visual diplay.

FIGURE 96. A giant dual-purpose tracking radar in the warning system can detect and track missiles at ranges exceeding 2,500 miles.

Warning systems must change to meet changes in the threat of enemy offensive systems. In the spring of 1960 concrete evidence was available concerning the feasibility of extending the range of aerospace warning systems when a Midas (Missile Defense Alarm Satellite) was launched. The combination of the Midas detection satellite, which contains infrared sensors to detect and report heat radiation from rocket-engine exhausts, and BMEWS, is expected to give about 30 minutes' warning of an enemy ballistic missile firing. A further refinement is expected from the Samos satellite in obtaining reconnaissance information while in a low, circular, polar orbit less than 200 miles from the surface of the earth.

Control Networks

SAGE.—The term SAGE stands for Semi-Automatic Ground Environment. Essentially, a SAGE unit is built around a huge electronic computer (Fig. 97) which has the ability to receive, remember, calculate, and transmit data instantaneously in the form of intelligible code on the face of electronic tubes similar to a television picture tube. Through various refinements, SAGE can be used either as a source of information, upon which instructions may be given to an interceptor, or SAGE can itself transmit coded instructions to autopilot equipment and actually steer the intercept course of a Bomarc missile or a manned aircraft equipped with data link apparatus.

Successful aerospace defense depends on speed: the speed with which the defense force can react to warning. SAGE brings to the defense system not only greater speed but also greater accuracy, reliability, and capacity. A SAGE direction center, along with the computer and other elements, constitutes a SAGE unit. The direction center is located in a two-story-high pit in the center

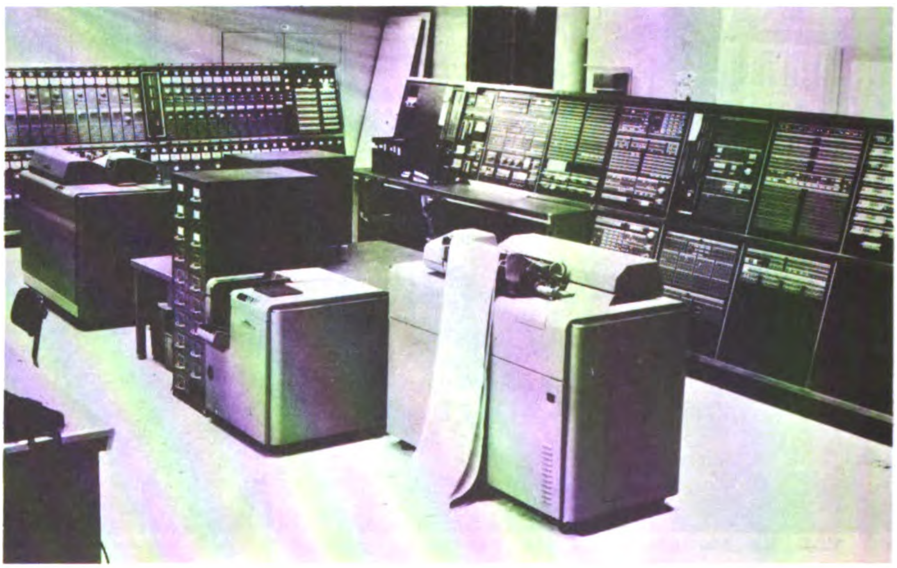


FIGURE 97. SAGE console equipment in detection center.

of a large, windowless building of blast-resistant reinforced concrete. Directly in front of the sector commander and his key staff officers is a large projection screen on which are flashed enlarged pictures from selected display tubes. The display tubes, of which there are a considerable number, contain geographical outlines of the area of which they are representative. On the face of these tubes appear letters, numbers, and words which have appeared as a result of the computations of the SAGE "brain." The commander may, with the push of a button, display the overall battle situation or any part of it he wishes to monitor in detail.

By selection, the commander may either have the information relayed vocally to the interceptor pilots, or, if the interceptor has the proper equipment, the computer itself may be directed to transmit instructions automatically to the interceptors, actually guiding them to an interception with a selected target. The computer, once initial information has been received, will have already calculated the speed, direction, altitude, and point of possible interception, and in addition, even suggest the most effective weapon to be employed: Bomarc, Nike, or jet aircraft interceptors. The decision, however, rests with the commander; the press of another button will send the interceptor on its way, with SAGE ready to guide it unerringly to the target.

The SAGE "brain" contains over 58,000 electronic tubes, each of which is air conditioned. Three 400-ton air-conditioning units are used to maintain a constant temperature of approximately 72° (Fahrenheit) in this area. Without the air conditioning, this temperature would climb to 150° in less than 2 minutes. The tubes are installed in the computer in pluggable units. If trouble develops, an entire unit of 8 or 10 tubes is removed and another installed; the faulty unit can be checked in the maintenance area later. To avoid breakdown due to faulty wiring, alternate routing on all circuits of a duplex communication system is used. There are 123 miles of internal wiring and 919 miles of external power and signal cables.

Each SAGE direction center has two electronic computers in operation 24 hours a day. Each receives and stores data simultaneously, one backing up the other in event of failure or periodic shutdown for maintenance. Although only one is engaged in active defense operations, the other unit continues to operate, checking the calculations of the active set, and ready to take over immediately if necessary, not only to maintain defense readiness in its own area but also to give NORAD's Combat Operations Center, to which all SAGE centers are connected, complete control of all areas, and the faculty of being able to use alternate SAGE centers if necessary.

MISSILE MASTER.—The U.S. Army counterpart of SAGE is the Missile Master (official designation, AN/FSG–1). All Missile Master sites, which coordinate and direct surface-to-air missile batteries, are tied in to the NORAD SAGE system. SAGE provides the Missile Masters with immediate information on the precise location and identity of aircraft or guided missiles within a defended airspace.

The Missile Master automatically informs each battery concerning targets be-

ing tracked by other batteries within the Missile Master complex. Each battery commander is thus enabled to select the most appropriate target, if cleared to engage the enemy, and avoid erroneous attack upon a target already engaged by another battery, or friendly objects within the area. Additionally, Master Missile equipment keeps NORAD's COC and Army Air Defense Command Posts (AADCP) advised of the operational status of the batteries.

During an actual engagement, the AADCP commander can direct a specific battery to engage a specific target in his immediate area. At the same time, through the same linkage which reports his operational situation to NORAD, the area Missile Master equipment receives a visual display, passed on to consoles in the batteries, which present a visual display of the current aerial situation. The display includes the location and identity of aerial objects in the overall area. The constant interchange of information gives commanders at various levels from the individual batteries up to the NORAD commander a continuing picture of the air battle, and each is thus enabled to make rapid decisions required for flexible operations and tactics. The rapid electronic coordination thus achieved assures optimum target engagement in seconds, without confusion, duplication, or unnecessary expenditure of weapons.

NORAD COMBAT OPERATIONS CENTER.—The NORAD Combat Operations Center (COC) at Colorado Springs, Colo., is the focal point of the NORAD system. This nerve center and hub of the vast defense system receives information within seconds from even the outermost posts of the farflung defense network. The COC is connected by the NORAD communications system to all its subordinate commands and to every command post on the continent and throughout the free world. From here an attack warning would be given to not only the NORAD forces but to Ottawa, Washington, D.C., Strategic Air Command, the Office of Civil and Defense Mobilization (OCDM), the Pentagon and other key military and civil agencies. The defensive battle for North America would be monitored from this operations center.

The COC supplies the trigger for action at the first warning of impending attack. Unknown aircraft tracks, unusual or suspicious patterns of air action, and other possible indications of an attack are closely followed. In short, the COC collects, displays, correlates, evaluates, and disseminates information of activities within the NORAD area of defense responsibility. To assist the staff of the COC in the all-important job of centralized combat reporting, several special control systems were needed.

A new electronic plotting system that represents the first major improvement since World War II in large-scale display of air traffic information is installed at the NORAD COC. The new system, known as Iconorama, has done away with the old methods of plotting and tracking aircraft. Formerly, the COC used a three-story-high, vertical, Plexiglas plotting and surveillance board. Technicians stood on various floor levels behind this large board and wrote the necessary symbology which displayed the information fed in through the communications net. The timelag in this method became most apparent during peak periods of activity and, of course, human error entered the picture on occasion.

Iconorama is an automatic electronic display system which uses a large, white screen—similar in appearance to those used in movie theaters. The system works with the SAGE system and allows observers to see, almost instantaneously, the position of airborne objects thousands of miles away. Tracks of both friendly and potential enemy aircraft in all areas covered by defensive radar networks will be visible. Iconorama has about quadrupled traffic-handling capacity, compared with that resulting from the old manual method of plotting. It has also reduced the manpower need by some 20 percent, and has all but eliminated the timelags of manual plotting.

Through an interlocked system of Iconorama, all information shown on the screen will be available to Strategic Air Command, the Joint Chiefs of Staff in Washington, and the Chiefs of Staff Committee (Canadian) in Ottawa, Canada, as well as to the NORAD Battle Staff. The two-dimensional screen depicts the tracks of various aircraft by individual, colored vectors. Impulses for the display are relayed for long distances over existing teletype lines, which has eliminated the cost of installing expensive transmission facilities. Iconorama can plot all the traffic information sent forward by SAGE.

In conjunction with Iconorama, information about approaching ICBM's can be flashed to the NORAD COC from the three Ballistic Missile Early Warning stations and portrayed along with the normal air traffic display. With BMEWS display fully operational, launch and impact areas, as well as alarm level, can be automatically shown. A central computer at the NORAD COC receives and evaluates the BMEWS information.

Although still under test at the time this book was written, indications were given that NORAD would be one of the "decision centers" benefiting from a proposed "nuclear blast alarm net." The alarm system plan proposes to have three detectors, placed at 120° angles around each of 100 or more possible missile target points. The detectors, engineered to prevent triggering by other than a nuclear blast, would work even if one of the three were itself destroyed. A flashed code impulse to the decision center would indicate the station hit and other status information. Thus, should an attack begin with nuclear detonations from otherwise undetected sources (e.g., so-called "suitcase bombs"), this warning net would not only provide immediate notification of such attack but also an excellent means of indicating areas which appear to be high on the enemy's priority list.

▲ **A SAC Commander briefs crew before taking off in B–52 for extended training flight.**

CHAPTER 11

STRATEGIC AIR COMMAND

Development and Operation

The capability of modern aerospace weapons and craft to disregard geographic barriers and national boundaries has forced the development of the present concepts of warfare. The decisive factor in any future total war, and for maintaining the peace, is still the capability for ultimate control of air and space. Hope for maintaining the peace, and countering effectively any initial attacks by an enemy, lies in building and maintaining, by the free world, a predominant weight of deliverable destructive weapons.

Strategic aerospace warfare is, by definition of The United States Air Force Dictionary, the use of aerospace weapons capable of combat and supporting operations

> "designed to effect, through systematic application of force to selected vital targets, the destruction and disintegration of the enemy's war-making capacity to the end that he no longer retains the ability or will to wage war."

The U.S. agency for such operations is the Strategic Air Command of the U.S. Air Force—familiarly known as "SAC."

THE MISSION OF STRATEGIC AIR COMMAND

The motto of the Strategic Air Command is "Peace is our profession." These paradoxical words actually state the first purpose of SAC. Because of its awesome striking power, SAC provides considerable assurance that its potential for destruction will not be used. This is the implementation of the policy of war deterrence to which the United States has been committed. This policy may be stated thus: if an aggressor is convinced that the retaliatory strength of his peacefully inclined enemy is greater than he can bear, he will not attack.

Through the bitter lessons of two World Wars, most of the countries of the world have learned that until all the peoples of the world are free to live without fear of aggression, the only peace which can last is one maintained by the strengths of nations whose policy is nonaggression.

The Strategic Air Command has a unique organization, best suited for carrying out its mission. Its purpose can be stated, with little extravagance, to be the preservation of the free state of men throughout that part of the world where freedoms are still common. SAC's mission is to be prepared to conduct strategic air operations on a global basis so that, in the event of sudden aggression, the command can immediately attack and destroy the vital elements of the aggressor's warmaking capabilities, to the extent that he will no longer have the will or ability to wage war.

SAC's peacetime objective is to maintain a force capable of deterring Communist aggression. This objective is a "negative" one: to establish and maintain a global offensive capability of such superior striking power that it minimizes the need for using it. At the same time, this command must be continually prepared to achieve successfully its "positive" objective: to retaliate decisively in case deterrence fails.

As SAC commander, Gen. Thomas Power lightly summarized his command's mission in this way: "What we're trying to do is get that Russian planner to get up from his planning table every day and say, 'Boss, I recommend you don't try it today.' " More formally he said elsewhere that "Our national policy is based on the proposition that war is not an acceptable method for settling man's arguments and that every effort must be made to maintain the peace—on honorable terms." Also, describing deterrence, he said it is "the determination of the American people to prevent and, if necessary, fight and win any kind of war, whether hot or cold, big or small."

Gen. Thomas D. White, speaking as Chief of Staff, U.S. Air Force, stated the case for preserving peace by deterrence this way:

> Since the prime purpose of our military forces is to prevent war, they will be most effective if we never have to use them. Our power, however, will be sufficient as a deterrent only so long as it convinces potential enemies that aggression against us and our allies is profitless.

Gen. Curtis E. LeMay summarized deterrence as follows:

> We maintain peace through unprecedented strength. By deterring war we insure peaceful existence with all peoples of the world until man can reach just and honorable solutions to his problems.

The deterrent concept—preventing an enemy from attacking by fear of consequences—is as old as man. In earlier days, before the great technological breakthrough, the doctrine of deterrence was relatively easy to proclaim and to carry out. It was not much more complicated than the words of President Theodore Roosevelt: "Walk softly and carry a big stick." Today, the "big stick" is not the sole possession of either the free world or the Communist bloc.

The Communists now control one-third of the world's people and one-fourth of its area. The United States remains one of the major barriers to Soviet achievement of world domination by any means whatever. To maintain a deterrent posture, the United States must (1) maintain carefully designed military forces sufficient in both quantity and quality to destroy the enemy's warmaking capacity and will to fight; (2) keep a high national resolve and determination to maintain such military forces and to use them if necessary; and (3) be certain that the potential enemy recognizes that this combination of strength and determination exists and is credible.

The Strategic Air Command is, of course, not the only deterrent force within our Military Establishment, but it contributes, and must continue to contribute, the major share of strength to the deterrent posture of the free world. If war should be forced upon the United States, over 90 percent of all the explosive power available to it would be carried in SAC aerospace vehicles. We have stated that the Strategic Air Command has the capability to destroy the warmaking capacity of any aggressor. In order to provide this capability, thousands of targets—over 20,000 of them—have been screened in analyzing the strengths and weaknesses of the Soviet Union and the Communist bloc. The Strategic Air Command knows what targets must be destroyed, and its war plans are based on this target analysis. The SAC strike force is not the only factor which deters aggression, but without a fully effective retaliatory force capable of inflicting on an aggressor damage which he considers unacceptable, there is no meaningful deterrent.

THE SAC ORGANIZATION

The Strategic Air Command is a specified command, a one-service command under the Department of Defense. The line of control for command of operational activities proceeds directly from the President through the Secretary of Defense to the commander in chief of the Strategic Air Command, with the Joint Chiefs of Staff acting as executive agent for the Defense Secretary. This direct line of control greatly strengthens the relationship of the President, as head of our Armed Forces, to the Nation's primary strategic striking force.

Headquarters for the Strategic Air Command is located at Offutt Air Force Base, Nebr. Subordinate to headquarters are three numbered air forces and a

missile division in the United States, and two air divisions and a numbered air force overseas.

The three numbered air forces in the United States are the 15th Air Force with headquarters at March Air Force Base, Calif.; the 2d Air Force with headquarters at Barksdale Air Force Base, La.; and the 8th Air Force with headquarters at Westover Air Force Base, Mass. Each has jurisdiction over roughly one-third of the command's combat units. Each air force and each of its combat wings is tactically self-sustaining.

Also part of the Strategic Air Command is the 1st Missile Division at Vandenberg Air Force Base, Calif. The division has the status of a numbered air force. One of its primary functions is to train missile units. After these units have demonstrated that they have reached an operational-ready status, they are integrated with bombardment units of the numbered air forces in the United States.

Overseas the Strategic Air Command has the 3d Air Division at Guam, the 7th Air Division in the United Kingdom, and the 16th Air Force in Spain. No combat units are permanently assigned to the oversea air divisions or to the 16th Air Force, but the oversea headquarters are responsible for the operation of the base or bases in their respective areas and must be capable of assuming control of the combat forces in the forward area during peacetime or wartime.

The size of the greatest single military force in the world is impressive. Total assets of the Strategic Air Command are almost a billion and a half dollars more than the total assets of the largest bank in the United States. They total over $12 billion, include aircraft, real property, equipment, inventories, and other assets.

Beyond the assets that can be evaluated in terms of dollars and cents is the great asset of SAC's force of skilled and dedicated personnel. This force exceeds more than 260,000 officers, airmen, and civilian employees. Of this group, 98 percent operate and support the combat force; 2 percent work in overhead positions.

Many of the personnel in the command are now gaining experience in another area—the missile force. With SAC's entrance into the missile field, more and more of its personnel became missileers. The vital role they now play in supporting the Nation's guided missile capacity is recognized and indicated by the Mark of the Missileers, a distinctive sterling-silver and blue badge worn on the left breast pocket of their uniforms.

THE BEGINNING OF SAC

From its rather hesistant beginning on March 21, 1946, at Bolling Air Force Base, Washington, D.C., to the present, SAC has been the free world's primary deterrent force. From an inadequate total of nine bombardment groups of B–29's (Fig. 98) and B–17's, and two fighter groups of P–47's and P–51's SAC has grown to become the most powerful military force the world has ever known.

In 1946, SAC had three jet aircraft assigned—P–80 Shooting Stars; since February 1959, the SAC bomber force has been completely jet powered.

Today, Strategic Air Command's power is almost impossible to describe except by comparison to a known or readily imagined scale: one SAC B–52 of today carries more blastpower than all the bombs dropped by all the aircraft employed in World War II—by both sides.

This massive, almost inconceivable, concentration of power did not emerge suddenly: it grew gradually, within the limits imposed by budgets and technological development. In May 1946, 2 months after its birth, SAC was given the responsibility of developing an atomic striking force prepared to conduct long-range operations in any part of the world. At this time the command was equipped with obsolescent B–17's and B–29's which were unable to carry out intercontinental missions from the United States: only one unit, the 509th Composite Group at Roswell Field, N. Mex., was capable of delivering atomic weapons.

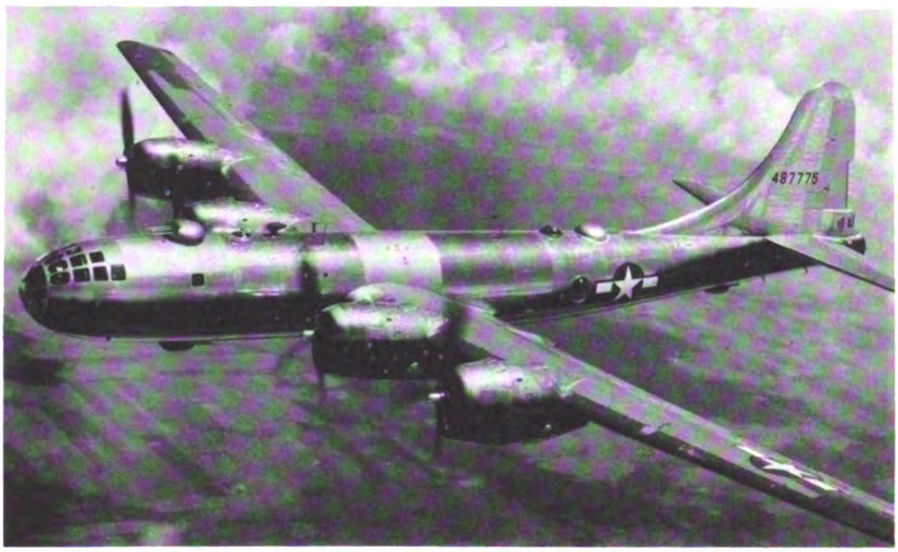


FIGURE 98. B–29.

Throughout 1946 and 1947, SAC expanded its operations and its assets, although by the end of 1947 few of the 16 bombardment or 5 fighter groups assigned to the command were fully manned or operational. The B–29's were still the backbone of bomber strength. The F–80 jet fighters became more numerous, reaching a total of 120 by the end of the year, but, because of range limitations, could not qualify as escorts for the bombers. Nevertheless, as relatively meager as the resources and manpower then were, during the year SAC squadrons rotated to the Far East. This rotation was the beginning of the development of SAC's present global mobility. In the latter part of the year, encouraging signs for the future of SAC were found in the flights of the first production model of the B–36 bomber and an experimental model of the B–47 jet bomber.

During 1948 the first improved postwar bombers, the B–36 Peacemaker and the B–50 Superfortress, were delivered to the command. The B–50 had greater speed and combat radius than the B–29, but was essentially only an advanced model of that aircraft. The B–36, on the other hand, was the largest bomber in the world and had almost an intercontinental range (Fig. 99). Before the end of the year, the F–80's were transferred to the Continental Air Command, and F–84 Thunderjets, fighters with a higher performance than the F–80, began to be assigned to the command. Lt. Gen. Curtis E. LeMay succeeded General Kenney as commander of the Strategic Air Command in October 1948 and shortly thereafter moved the headquarters to Offutt Air Force Base, near Omaha, Nebr. General LeMay remained as commander until 1957—the longest tenure of major command in the history of the Air Force.

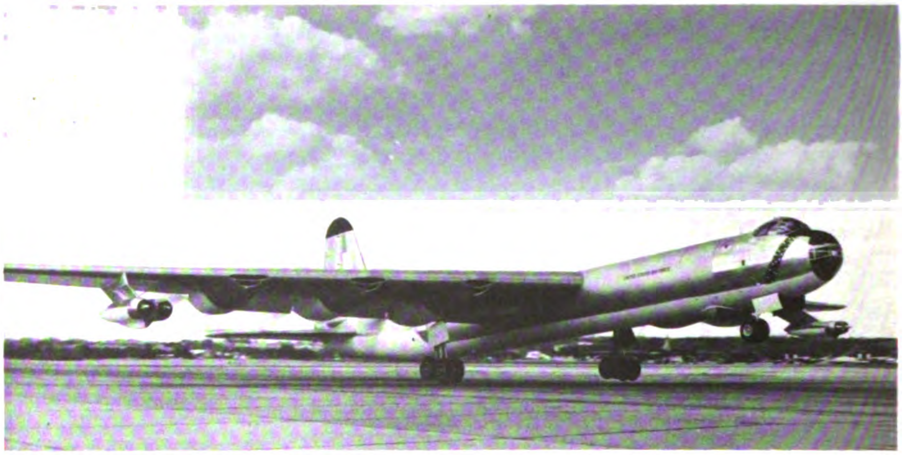


FIGURE 99. B–36.

Early in 1950 the entire command was reorganized and realigned. The three subordinate air forces were each assigned bombing and reconnaissance missions and given jurisdiction over SAC combat units based in specific geographical regions of the United States: 2d Air Force, the eastern section; 8th, the central; and the 15th, the western. With each air force containing both bombardment and reconnaissance units, the air forces had a balance and flexibility they had not had before. At the time SAC also had fighter wings for escort duty.

The Strategic Air Command entered the Korean conflict in July 1950. Nine days after being ordered to the Far East, SAC bomber units were operating in Korea, where they flew over 20,000 sorties in attack and reconnaissance missions.

THE MODERNIZATION AND EXPANSION PERIOD

In maintaining its deterrent capability, the Strategic Air Command is faced with four problem areas: the dramatic advance in military technology; the

gradual increases in the Soviet's defense capability; the fantastic compression in time—warning time and reaction time; and the problem of survival of SAC's strike capability in case of a sneak attack by bombers, missiles, or both. The modernization process, which may be said to have begun in 1950, undertook not only modernization of equipment but ideas for the protection and utilization of equipment. Some of these advances will be examined here.

Not until 1950 did the Air Force have the resources required to modernize and to expand the Strategic Air Command. After June 1950 the rearmament incident to the Korean war permitted the command to reequip its bombardment units with jet aircraft much more quickly than would otherwise have been possible. The first B–47 Stratojets were assigned late in 1951 and were used to form new bombardment wings.[1] The performance of the six-engine medium jet bombers exceeded that of SAC's other bombers.

In 1953, B–47's began replacing B–29's and B–50's. By the end of 1954 all B–29's had been phased out, and by mid-1955 all B–50's had been retired from bombardment units. In 1955 the huge B–52 Stratofortress all-jet heavy bombers began to replace the B–36's in the command. Two years later SAC's six strategic fighter wings and their supporting KB–29 tanker planes were transferred to the Tactical Air Command in order to consolidate and strengthen the fighter-bomber force within the Air Force. SAC became an all-jet bomber force in February 1959 when the last of the command's B–36 reciprocating engine bombers was retired. The B–36 was the first aerial strategic weapon system to be retired without ever having fired a shot or dropped a bomb in combat.

Oversea Expansion and Realignment of Continental Forces

After the Korean war, the Strategic Air Command acquired the rights to more oversea bases and secured direct control of oversea areas vital to its operations. SAC bombardment units had been present most of the time since 1948 in the United Kingdom, and in March 1951 the command activated the 7th Air Division in England. The 5th Air Division, which was activated at Offutt Air Force Base early in 1951, was reestablished at Rabat, French Morocco, in June 1951. In 1954, the 3d Air Division was activated at Anderson Air Force Base, Guam. Because of the growing importance of the oversea bases, in mid-1957 the command established its first oversea air force, the 16th, in Spain, and the 5th Air Division was placed under its control. Also in this same year, the 8th Air Force assumed direct control of a number of bases and smaller installations in Newfoundland, Labrador, and Greenland (Fig. 100).

While strengthening its position overseas, SAC was also reshuffling its forces in the continental United States to increase its effectiveness. For example, the northeastern section of the United States began to figure more prominently

[1] In 1948 the wing replaced the group as the basic, self-contained unit. Since then the Air Force has measured its strength in terms of wings instead of groups.

in SAC's strategic plans as a base of operations against oversea targets; obviously certain European targets were closer and could be reached by bombers more quickly from bases in New England than from bases in the Southwest. Moreover, from New England bases, bombers would require fewer refuelings or stops. Consequently, in 1953 SAC moved the 8th Air Force headquarters from Carswell AFB, Tex., to Westover Air Force Base, Mass. The 8th immediately moved additional bombardment wings into the area.

FIGURE 100. B–47's lined up for a predawn takeoff from Thule Air Base, Greenland.

The move of the 8th Air Force brought with it certain shifts in the geographic areas of responsibilities for the numbered air forces. The 8th was now responsible for bases, units, and personnel in the northeast and north-central portions of the United States; the 2d Air Force assumed similar responsibilities in the southeast and south-central portions; and the 15th Air Force, the West.

The Role of Aerial Refueling

Moving the bombers placed them closer to their potential targets and, as we noted, reduced the number of refuelings or stops. But in the absence of an intercontinental bomber, something more was needed than the move of bombers to the northeastern section of the United States. In strategic bombardment one of the most important factors has always been combat radius—the maximum distance a plane can fly to the target with a bomb load and return. The combat radius is usually less than 40 percent of combat range because of the time required over the target and the time required for return to base. In World War II the B–17 and B–24 had a practical combat radius of 600 to 800 miles. The B–29 extended the radius to 1,600 miles during the war. Obviously, without bases in England and the Marianas, these planes could not have carried out sustained strategic bombardment campaigns against Germany and the Japanese home islands.

Even the B–36 and the B–50 did not have sufficient combat radius to permit them to reach targets in Europe or Asia. The oversea bases which were acquired served as steppingstones to the targets, but these bases were vulnerable to attack. Consequently, it was imperative for the command to provide another means of enabling its bombers to perform extremely long-range nonstop flights. To accomplish this, SAC in 1948 turned to a technique which had first proved practical a quarter of a century before—aerial refueling. The midair transfer of 25 gallons of fuel in 1923 was the birth of an operation that now involves the pumping of more than 243 million gallons of fuel per year in SAC.

In 1948, for the first time in Air Force history, in-flight refueling was used in organized missions to extend the range of tactical bomb units. As a part of the program, SAC organized two refueling squadrons, using converted B–29 and B–50 bombers as tanker planes. Early in the next year a B–50 bomber, Lucky Lady II, dramatized the military possibility of aerial refueling, when it became the first aircraft to fly nonstop around the world. The bomber covered a distance of 23,452 miles in 94 hours and 1 minute. The plane was refueled in flight over the Azores, Arabia, the Philippines, and Hawaii.

Development of an aerial refueling capability within the command was accelerated in 1951 when SAC received its first KC–97 Stratotanker—a 4-engine, double-decked aircraft carrying 15 tanks of transferable fuel and equipped with a fuel transfer boom.

With the delivery of B–47 Stratojets to SAC's medium bomb wings, intensive aerial refueling training began. By 1953 the sweptwing jet bombers and fuel-laden tankers were completing an aerial hookup somewhere in the world every 15 minutes. By 1955 a completion rate of one every 3½ minutes had been reached.

Because the KC–97, powered by conventional piston engines, could not refuel SAC's force at jet bomber speeds and altitudes, development of a jet tanker was begun. The first jet engine tanker, the KC–135 jet Stratotanker, was delivered to SAC in June 1957.

Recent Developments

The Strategic Air Command has continued to increase its inventory of KC–135 jet Stratotankers. In 1959, KC–135 strength increased to 17 squadrons. The command has also continued to increase its strength and range with the B–52 Stratofortress, which was first delivered in 1955. During that year the last of the B–50 Superfortresses was phased out of the inventory.

The force is constantly being modernized. Early in 1959 the first Boeing B–52G was delivered to the command. This aircraft was designed as a "multiple punch" weapon system, encompassing the advantages of direct human control for on-the-spot decisions and the strike capabilities of a missile. Armed with the Hound Dog rocket missile, which has a range of several hundred miles, the B–52 is able to destroy enemy defense installations that obstruct penetration to primary targets. The missiles can also be directed against primary targets without exposing the aircraft to local defenses.

Planning for the inclusion of a missile force in the Strategic Air Command began several years ago. For example, as early as 1951 SAC became involved in monitoring the development of several missiles. Missiles took on added significance in the command's plans and programs when late in 1957 Headquarters USAF assigned the responsibility for the initial operational capability of intercontinental and intermediate range missiles. Immediately the command activated the 1st Missile Division to control ballistic missiles designed for strategic air operations. In this same year, the first guided-missile squadron was activated and based at Presque Isle Air Force Base, Maine, equipped with the SM–62 Snark.

In 1959, four squadrons of SM–75 Thors were deployed in England, and the SM–78 Jupiter system programed for Italy and Turkey with crews trained by SAC. The Atlas ICBM became operational in limited numbers at Vandenberg

FIGURE 101. The Titan ICBM during a development stage.

Air Force Base, Calif. The first operational Atlas was fired from Vandenberg Air Force Base in September 1959 by a SAC crew. The Atlas squadron at Vandenberg was integrated into SAC's emergency war order with a capability to launch within 15 minutes. At that time substantial progress had also been attained with another long-range strategic missile, the ICBM Titan, which in test firing placed the nose cone on a target 6,000 miles from the launch pad (Fig. 101). Continuous research in the development of more advanced aerospace systems, such as Samos, Midas, and Dyna-Soar, provides an excellent base upon which the Air Force builds its space efforts. Strategic Air Command looks ahead and provides for the day that it may become the Strategic Aerospace Command.

Today, the Strategic Air Command is a blend of forces with its bombers, tankers, and missiles (Fig. 102). For the present and for some time to come, SAC will depend heavily on manned weapon systems to carry out the strategic mission because only trained human intelligence can discriminate between and move to

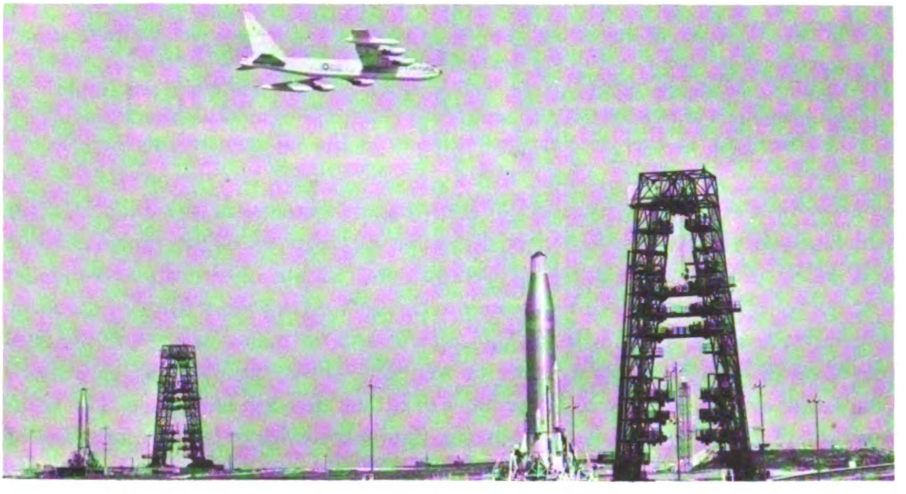


FIGURE 102. SAC's mixed force concept is shown as a B–52 flies over an Atlas missile installation.

destroy moving, protected, or hidden targets that are not feasible or economical for an attack by ballistic missiles. But SAC is rapidly building up its missile capability. Intercontinental ballistic missiles and manned intercontinental bombing systems are not competing but are complementary. Each system has inherent disadvantages which cancel out the other in a mixed force, whereas the disadvantages are compounded in a force wedded to one system or the other on an "either-or" basis. Missiles have capabilities that bombers do not have, and vice versa. Moreover, mixed force requires the potential enemy to effect a counter to any and all combinations of weapons.

The missile's major advantage over the manned bomber is the missile's far greater speed which provides the valuable element of surprise; presently there is

no adequate defense against a missile attack. As its advantages increase, the ballistic missile will play an extremely important part in our force structure.

First-generation operational missiles obviously had definite limitations in comparison with the manned system. Once launched at a target, these missiles cannot be recalled (they can only be destroyed—an expensive way of halting an attack or changing plans) nor can these missiles be directed from the original target to another after launching. Another serious limitation of an all-missile force is that a missile cannot relay intelligence back to its launching site as to the damage inflicted when it has hit the target. Manned systems provide reliability under the worst conditions, flexibility in the choice of targets, and flexibility in tactics.

Thus, it is clear that the first-generation missile could only supplement the manned vehicle—not replace it. But the mixed force enabled the Strategic Air Command to create a highly flexible force with the most suitable available weapon system assigned to the most specialized strategic mission.

General White expressed the philosophy of the mixed force as follows:

> The Air Force objective has been—and continues to be—to obtain the best aerospace weapons in the quantities needed for our national security. . . . This requires a blend of type, quality, and quantity within each given time cycle. Thus, the mix of weapons will be continually changing—it must because it would be dangerous to ever consider any weapon as the ultimate or invulnerable weapon. . . .

The Air Force bases its selection of weapon systems on the functions for which it must provide forces. It must tailor its weapons to the missions to be performed. Today we rely primarily on a combination of aircraft and missiles to perform our mission. We will soon see this mix change to a force of carefully dovetailed systems that will include space systems along with aircraft and missiles. We must possess a mixture of weapons which can block an aggressor's chances of success via any or all avenues of attack through aerospace. The composition of this force must of necessity fluctuate—with relative quantities of missiles, aircraft, and spacecraft changing as the state of the art advances for each kind of vehicle and its related systems.

The Strategic Air Command has plotted its course carefully, laying plans for the gradual turnover of the strike force from bombers to missiles according to a detailed plan which can be altered if circumstances merit change. The command knows there must be no gaps in its strength, even gaps created by change which will eventually bring improvement.

General LeMay summarized SAC's position when he stated, "We're not married to planes or missiles. We're married to getting the job done."

Dispersal and Hardening of Installations

If the Soviet Union should increase its striking capability and the Strategic Air Command neither improved its force nor made its combat units less vulnerable to attack, SAC's deterrent power would be largely lost. In any event, it would be lost the moment the enemy felt that a surprise nuclear attack would deprive the command of a sufficient retaliatory force to strike back with a

decisive blow. In this circumstance, there would be a strong temptation for an enemy to gamble with an attack on the United States.

To prevent such a situation, SAC has undertaken two major steps: dispersal and "hardening" of the force, and mounting a constant runway alert. Robbed of the element of complete surprise, and faced with attacking many widely dispersed targets, the enemy has no chance of destroying the bulk of SAC's forces with one blow. If he cannot destroy the Strategic Air Command with one blow, the enemy will not likely commit national suicide by attacking.

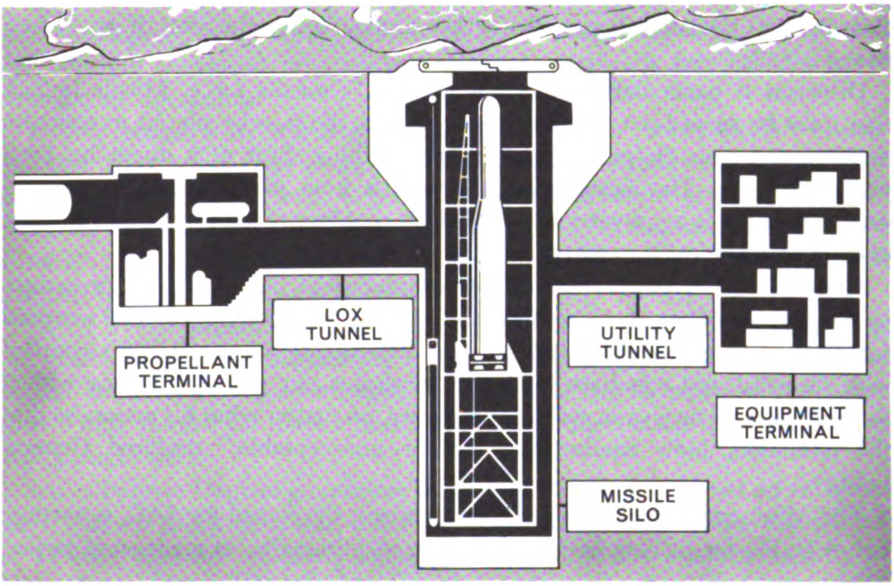


FIGURE 103. Typical Titan launch station.

In the event of enemy attack, SAC bases would undoubtedly be top-priority targets, since these installations contain this country's major counteroffensive weapons. The necessity for launching as much of our retaliatory force as possible, under conditions of warning ranging from a few minutes downward, is a paramount consideration. The dispersal program spreads the force over a greater number of bases and thereby complicates the enemy's problem of destroying the entire strike force in one blow. This fact lowers an aggressor's confidence that he can hit this Nation with impunity. The use of more bases also makes more runways available for launching the force, enabling SAC to get more aircraft off the ground in less time.

Heavy bomb wings of 45 B–52's are divided into strategic wings of 15 bombers and 10 tankers for dispersal purposes. The strategic wings are assigned to SAC-owned bases or as tenant units on bases of other commands. The objective is to have no more than one strategic wing or more than one B–47 or B–58 wing, with its tankers, located on any one base. SAC also developed a further dis-

persal plan for portions of its B–47 fleet. Small B–47 detachments are regularly programed to use civil airfields for short periods of operation. This random dispersion of the B–47 fleet further complicates any enemy surprise attack problem.

In addition to providing more runways, SAC is constantly developing techniques to reduce takeoff intervals for aircraft. Under the Open Road project, B–47 takeoff intervals were reduced from 1 minute to 15 seconds. KC–97's reduced their takeoff intervals to 10 seconds. Previously it had been thought that exhaust smoke and turbulence left by a heavy aircraft must be allowed to clear before another could take off. The tests indicated that crews have little trouble with smoke or turbulence in close-interval takeoffs. This added capability of close-interval takeoff will provide further protection for the aircraft against an enemy attack.

Dispersal is particularly important for SAC's missile force. Missile launch sites must be spread out and hardened; that is, the missiles placed in concrete underground sites designed to withstand anything short of a direct hit by a nuclear weapon. Hardening of missile sites is both practical and highly desirable because it aggravates an aggressor's problem of destroying all or most of our missiles before they can be launched against him.

Higher levels of hardening will be introduced as required. This procedure increases the number of enemy weapons required to between 20 and 40 weapons for destruction of a single hardened site. "Hardening of our ICBM's coupled with dispersal and adequate force size, confronts our potential enemy with a force which will survive in sufficient quantity, no matter what his action, so that the retaliatory blow against him will be unacceptable," declared General LeMay.

The Minuteman, the greatly simplified missile developed for SAC, is particularly suitable for placing in hardened sites. Additionally, as mentioned earlier, Minuteman missiles can be mounted on railroad cars and moved in a random pattern over the almost 100,000 miles of railroad trackage in this country.

The Alert Force

The alert system has been described as the very backbone of SAC's deterrent strength. Several years ago the Strategic Air Command recognized the fact that eventually it must be able to launch its strike forces within minutes—or die on the ground. The moment this capability would become vital depends upon the enemy's technological progress in the development of weapon systems.

Plans for an immediate launch capability were begun in the command's earliest days and were implemented for the first time on October 1, 1957, when a limited number of SAC aircraft went on 24-hour-a-day alert. The Command has attained its goal of having one-third of the strike force airborne within 15 minutes after warning of attack.

Our present air defense system could provide enough warning of a Soviet bomber attack to permit large numbers of SAC bombers to be launched for the counterattack before their bases might be struck. But SAC must be prepared to

react with a minimum of warning time, and so alert crews at bases all over the world are prepared to go into action at a moment's notice.

Operation of the alert force requires a tremendous amount of hard, never-ending work. Bombers on alert are parked near the end of the runway. Maintenance crews constantly check and recheck each item of equipment and each part of the aircraft, so that it is ready to start its takeoff roll at a moment's notice. Bomber crews pull shifts of alert duty around the clock; they sleep and eat near their aircraft. They are thoroughly familiar with their targets, their routes, and their split-second schedules. Detailed and up-to-date information on every phase of their missions is provided through the unique combination of SAC's worldwide intelligence and weather systems, its global communications network, and the centrally controlled organization designed specifically for the conduct of strategic air operations.

Within seconds after warning of an attack had been received at SAC headquarters, alert crews everywhere would race to their aircraft which are fueled and loaded with bombs, ready to go. A few minutes later, the first bomber would be on its way to its predesignated target. Soon, the entire alert force would be airborne, and with every minute of warning beyond 15 minutes, additional SAC bombers would follow in rapid succession.

SAC's global organization, its singular facilities for aerial refueling, and the extensive network of bases are vital advantages which the Soviets do not possess. Because of these advantages, the alert force can be expected to retaliate with telling results, no matter how massive and unexpected a Soviet bomber attack might be.

SAC's Positive Control guarantees that the bombers, if launched on an actual alert, will not touch off a war under a false alarm warning. Under the dictates of Positive Control (formerly called Fail Safe), SAC's bombers will fly to certain points well short of enemy territory and turn back to their bases unless instructed otherwise by coded message. The decision for SAC bombers to go on to their targets and to expend their nuclear weapons must come from the President.

The oversea portion of the worldwide ground alert operation is referred to as "Reflex Action." Under this concept SAC crews from stateside bases are deployed to oversea areas for a short time. (Previously, complete wings rotated for 45–90-day periods.) There are, however, still occasional longer periods of temporary oversea duty for some SAC units.

The Reflex Action system gives us a true effective alert force in oversea areas since crews meet their training requirements flying over and back and devote their entire time to maintaining the alert posture at the oversea bases.

The worldwide ground alert posture has proved its worth many times over as a major deterrent instrument. But a period is approaching rapidly when we may not get a 15-minute warning, the minimum needed to launch SAC's ground alert force. We may not get any warning at all if the Soviets succeed in accumulating a sufficient stockpile of ballistic missiles to venture a missile attack before we have in operation reliable missile warning systems. Such sys-

tems are now under development and, when perfected, are expected to give us the required 15 minutes' warning of a missile attack.

Meanwhile, then, SAC's problem is to insure the survival of its alert force on the assumption that there will not be any warning at all. High-ranking Air Force officers have advocated an airborne alert as the solution to this problem. General Power has stated:

> Surprisingly enough, this complex problem can be solved through a basically simple expedient; namely by keeping the alert force in the air. Obviously, an airborne alert needs no warning whatever, will survive even the best planned missile attack and needs no more time to start the counterattack than it takes to change course to the target.
>
> SAC has tested the airborne alert principle very thoroughly and found it to be entirely feasible and practical. In contrast to other types of countermeasures, which normally require years of extensive research and development the airborne alert can be implemented with existing and operationally proven equipment.

Congress has authorized the President to order an airborne alert of the Strategic Air Command at any time he sees fit. In addition, initial funds to buy spare engines, electronic gear, and other spare parts required for this operation have been allocated. General Power testified at a budget hearing:

> With adequate and timely preparations for meeting added demands for support, SAC can maintain an airborne alert long and effective enough to bridge what could otherwise become the most dangerous gap in our military posture since Pearl Harbor.

The incorporation of missiles into SAC does not cancel the need for the ground and airborne alert forces. As far into the future as SAC planners can see, manned aircraft will be needed along with missiles to give the command a flexibility of operation impossible to attain by relying solely on one weapon system. The alert concept will also be applied to the missile force as it becomes operational.

CURRENT EQUIPMENT

In February 1959, when the Strategic Air Command became an all-jet bomber force, strategic air operations were geared entirely to the increased speed of jet aircraft. The jet bomber force, through aerial refueling, has global range. The complete force is composed of approximately 2,000 B–47's and B–52's, plus about 1,000 KC–97's and KC–135's, with B–58's replacing the B–47's at an undisclosed rate.

Bombers

As we have noted, the bomber force of the Strategic Air Command is made up of B–47's, B–52's, and B–58's (Fig. 104). Another bomber which is not currently in SAC's inventory is the B–70.

THE B–47 STRATOJET.—The 600-mph B–47 Stratojet, a medium bomber, makes up the bulk of the Strategic Air Command's war-deterrent force. Designed to carry nuclear devices and powered by six jet engines, the Boeing

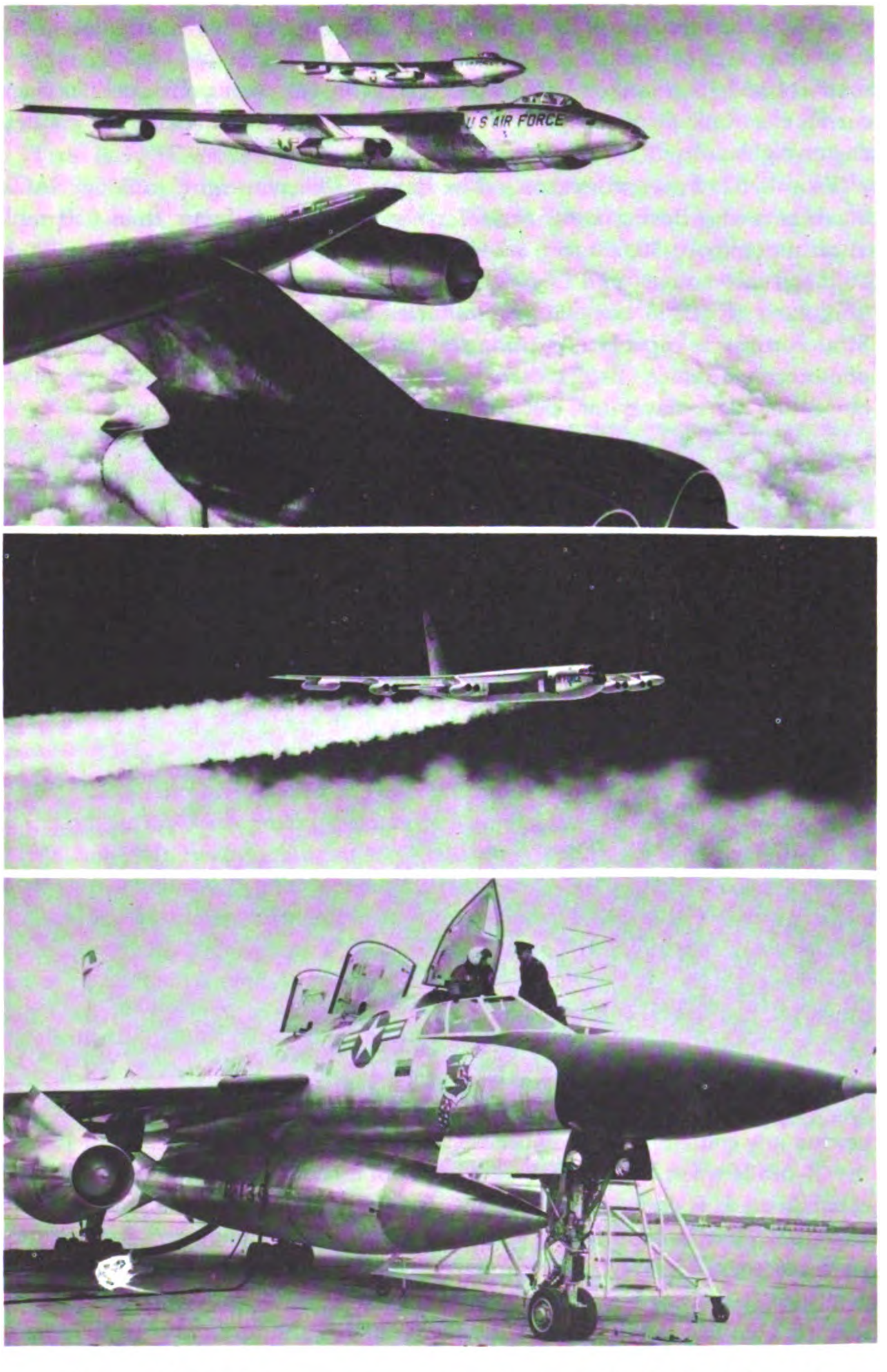


FIGURE 104. SAC's current bomber equipment, the B–47, the B–52, and B–58.

Stratojet cruises at altitudes above 40,000 feet with a range of more than 3,000 miles without refueling. Through in-flight refueling, the B–47's original 3,000-mile range was expanded to a point limited only by the endurance of its three-man crew; it can strike virtually any target in the world. Its sleek fuselage carries electronic devices capable of seeking out a target in any kind of weather, day or night.

THE B–52 STRATOFORTRESS.—The present "heavyweight" among SAC's bombers is the Boeing B–52 Stratofortress that travels faster than 650 mph at altitudes above 50,000 feet. Its eight jet engines produce as much power as 30 diesel locomotives, and its fuel capacity, greater than that of three railroad tank cars, gives the bomber an unrefueled range of about 6,000 miles. The Stratofortress is capable of carrying a nuclear payload and can be used for photoreconnaissance. B–52's carry a crew of six: aircraft commander, pilot, navigator, radar navigator, electronic warfare officer, and tail gunner.

A newer version of the Stratofortress, called the B–52G, became America's first missile-carrying bomber with two GAM–77 Hound Dog missiles on each side of the fuselage and a nuclear payload in its bomb bay. The missiles can be set for predetermined targets and are equipped with an internal guidance system which ignores enemy radio and radar-jamming efforts. With this added striking power, the B–52G can launch its missiles to wipe away enemy defenses barring the path to the bomber's primary target area. SAC accepted first deliveries of this aircraft in February 1959. In April 1960 one of the B–52G bombers flew from Florida to the North Pole and back to Florida and then launched an air-to-surface Hound Dog missile as the climax of the 10,800-mile trip.

The B–52H missile-carrying bomber, which became operational in 1961, features an advanced automatic defensive armament system. A six-barreled Gatling gun, capable of firing 4,000 20-mm shells per minute, replaces the four 50-cal. machineguns carried in the tails of earlier models. The hydraulically operated Gatling gun is electronically controlled by a fire control system which requires the operator only to pull the trigger. Among a number of other important changes, the new bomber is powered by turbofan engines which increase the range of this model well beyond that of the B–52G; equipped with more advanced electronic equipment; and given the capability of carrying the solid-fuel, long-range, hypersonic Skybolt ALBM.

THE B–58 HUSTLER.—A new jet bomber capable of altitudes and speeds far beyond any contemporary bomber began entering the inventory early in 1960—the B–58 Hustler, the world's first supersonic bomber with intercontinental capabilities. It is designed to carry nuclear weapons at twice the speed of sound (mach 2). The B–58, destined to replace a part of the command's B–47 Stratojet force, requires only a three-man crew—pilot, navigator-bombardier, and defensive systems operator. SAC crews were trained to provide the command with its own instructor-crews as the B–58 entered the inventory. In the spring of 1960 a test force crew flew the Hustler 11,000 miles in 18 hours and 10 minutes. Most of the flight was made at 620 mph, with two in-flight refuelings.

In January 1961 a B–58 Hustler automatically set five new world records for lesser distances and smaller loads while setting still another record of flying a 2,000-km (1,242.7 mi.) closed course with a payload of 2,000 kilograms (4,400 lbs.) at an average speed of 1,061.808 mph. It covered the first 1,000 km at a speed of 1,200.914 mph.

THE B–70 VALKYRIE.—The B–70 Valkyrie, initially scheduled to replace some B–52's, is a far-advanced aircraft with a maximum speed three times the speed of sound, an altitude of more than 70,000 feet, and a range exceeding the 6,000-mile range of the B–52. The Valkyrie was designed to deliver any weapon in the Air Force inventory—air-launched ballistic missiles, a "train load" of standard bombs, a series of hydrogen bombs for multiple targets, or a combination of bombs and missiles for sequence attacks (Fig. 105).

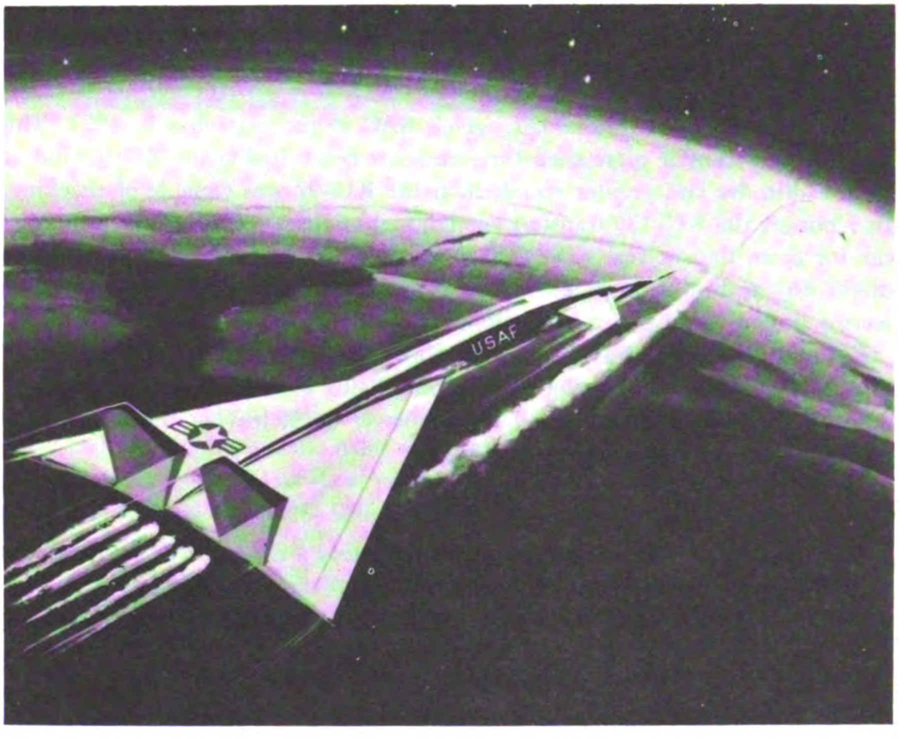


FIGURE 105. A conception of the B–70 "Valkyrie" launching a missile.

The name "Valkyrie" is appropriate for this advanced aircraft. In Norse mythology, the Valkyrie were maidens of extreme beauty who ranged the heavens on their steeds and conducted the souls of heroes slain in battle to Valhalla.

The original program envisioned construction of 13 complete B–70's with bombing, navigation, and countermeasures systems, with a likely flight date of

the prototype in 1963. After a number of cutbacks due to budgetary slashes, the program was largely restored to its original form late in 1960. In early 1961 the budget was again cut back.

Tankers

As stated earlier, the air-refueling force of the Strategic Air Command consists of the KC–97 Stratotanker and the KC–135 jet Stratotanker.

THE KC–97 STRATOTANKER.—The workhorse of SAC's tanker fleet, which made it possible for the jet bomber force to fly nonstop against any target in the world, is the KC–97. Since SAC received its first KC–97 in 1951, the command placed almost 950 of the big tankers into operation. The Stratotanker cruises at 350 mph and operates above 35,000 feet. Fuel is transferred from tanker to bomber at 600 gallons per minute through a telescoping flying boom attached to the underside of the tail. A boom operator, one of the five-man crew, controls the position of the boom by raising and lowering it or flying it from side to side by means of movable air fins.

THE KC–135 JET STRATOTANKER.—The KC–97 eventually will be replaced by the KC–135 Jet Stratotanker, which SAC began receiving in 1957. The KC–135 can transfer more than three times as much fuel as the KC–97 and at higher altitudes and greater speeds than the KC–97 was capable of reaching. In 1 minute the KC–135 transfers enough fuel to operate the average passenger car for more than a year. The tanker carries enough fuel to last the average driver 46 years, and, in 8 minutes, it can transfer more fuel than a gasoline service station could pump in 24 hours of steady operation.

This jet tanker can travel at speeds above 550 mph and can operate above 42,000 feet. It has a streamlined telescoping flying boom used in fuel transfers. Aerial refueling equipment is all on the lower deck, leaving the upper deck clear for cargo or troop carrying services.

Helicopters

The Strategic Air Command has in its inventory a new type of aircraft—the H–48B helicopter. Holder of the world altitude mark in its category, this craft is used primarily for crash-rescue work and missile support operations (Fig. 106).

Intercontinental Cruise Missile (ICCM)

The first strategic intercontinental guided missile to reach operational stage is the SM–62 Snark, a pilotless aircraft which flies at near-sonic speeds to a range of 5,500 miles. The Snark can be zero launched from a stationary or mobile launcher. The missile and launcher can be flown to any point in the world within a few hours. This intercontinental cruise missile is a high-altitude, sweptwing, single-engine, jet-propelled missile with self-contained and non-jammable guidance equipment. Relatively few Snark missiles were produced because the Snark program was overtaken by fast-moving developments in ballistic missiles.

FIGURE 106. Simulated rescue operation is carried out by SAC H-43B helicopters.

Intercontinental Ballistic Missiles (ICBM)

The intercontinental ballistic missiles in SAC's inventory are the SM-65 Atlas, the SM-63 Titan, and the SM-80 Minuteman.

SM-65 ATLAS.—The Air Force's first intercontinental range ballistic missile, the SM-65 Atlas, was assigned to the Strategic Air Command's 1st Missile Division immediately upon becoming operational. Powered by liquid-propellent rocket engines, the hypersonic Atlas was designed to deliver a high-yield nuclear warhead to targets 5,500 nautical miles away in about 33 minutes. This ballistic missile has a speed of over 16,000 mph at burnout and an altitude of 920 miles at the highest point (Fig. 107).

SM-68 TITAN.—The SM-68 Titan became the Air Force's second ICBM developed for use by SAC. A 15,000-mph liquid-propellent missile, Titan was programed to provide a two-stage ICBM to carry the heaviest possible conventional or nuclear payload. A distinct advantage over the Atlas was sought in developing an operational ICBM which could be positioned at underground launching sites which provide maximum protection against an enemy nuclear attack (Fig. 108).

SM-80 MINUTEMAN.—The third Air Force intercontinental ballistic missile for SAC's inventory is the three-stage solid-propellent SM-80 Minuteman. Simplicity of storage and maintenance allows the missile to lend itself more readily to hardening, whereby it can be protected underground to withstand explosive attack of all but a direct hit. Because this ICBM is readily adaptable also to mobile launchers, a portion of this force is scheduled for deployment on railroad cars to move at random from place to place throughout the country's

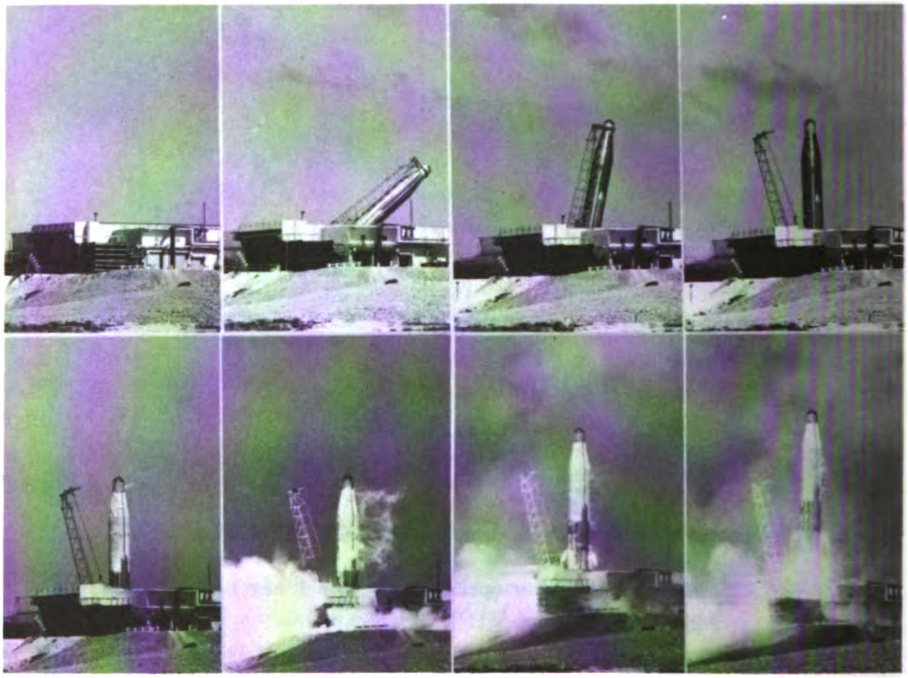


FIGURE 107. This launching of an Atlas ICBM was accomplished in 15 minutes by SAC missilemen.

vast rail network (Fig. 109). Minuteman missiles were specifically designed to be housed in hardened underground shelters widely dispersed, fully automatic, and capable of almost instantaneous reaction to enemy attack. One of the greatest advantages of the Minuteman is that it requires no one to attend it. Another advantage is that the Minuteman missiles are relatively cheap and can be produced in large numbers. Because of this fact and because of their dispersal, it would be mathematically impossible for an aggressor to destroy them all. This factor should strongly deter a potential aggressor.

Intermediate Range Ballistic Missiles (IRBM)

The intermediate range ballistic missiles assigned to the Strategic Air Command are the SM-75 Thor and the SM-78 Jupiter, both of which are deployed overseas and are not placed at sites in this country.

SM-75 THOR.—The SM-75 Thor is a single-stage, intermediate-range ballistic missile, liquid fueled and capable of exceeding a 1,500-mile range. The missile attains a speed of about 10,000 mph, employs an all-inertial guidance system, and can carry a nuclear warhead. This IRBM can be transported by U.S. Air Force planes, a capability which gives the Thor an advantage of strategic mobility. It is transportable on a trailer (transporter-erector) which also serves

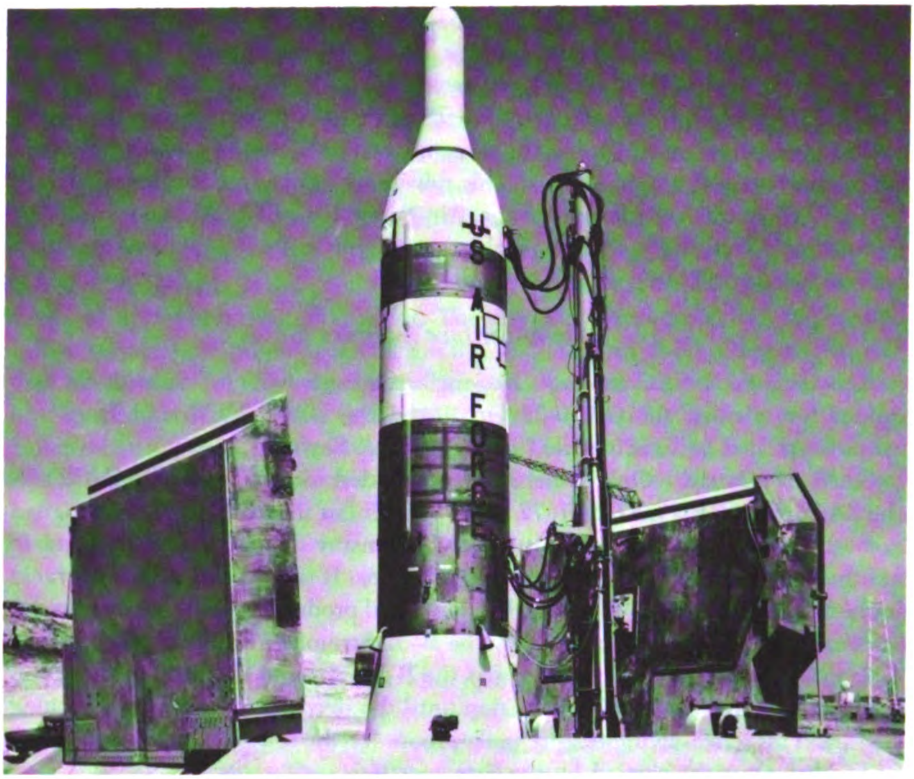


FIGURE 108. An Air Force Titan ICBM rises from its underground silo in a checkout test.

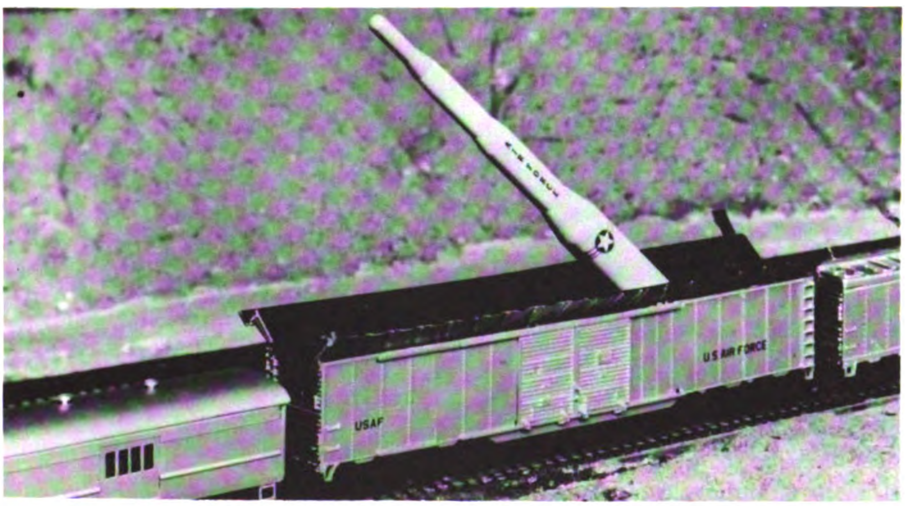


FIGURE 109. An early depiction of the mobile Minuteman train.

as the missile erecting arm. Thor's versatality and reliability permit its use not only as a single-stage ballistic missile weapon system, but also as the first stage for research and development projects of a special nature. Thor became America's first IRBM to be deployed overseas.

SM–78 JUPITER.—The second intermediate range ballistic missile is the hypersonic SM–78 Jupiter, which has the same mission as Thor: to destroy targets at ranges up to 1,500 nautical miles. This missile, developed at Redstone Arsenal by the Army, was transferred to the Air Force for operational control. The liquid-propellent missile, with its single-stage engine and self-contained guidance system, is launched vertically from ground pads.

Air-to-Surface Missiles

Also assigned to SAC are the air-to-surface missiles, which consist of the two guided air missiles, the GAM–72 Quail and the GAM–77 Hound Dog, and an air-launched ballistic missile, the GAM–87A Skybolt.

GAM–72 QUAIL.—One of the first two guided aircraft missiles (GAM) in the SAC inventory is the GAM–72 Quail, which is a short-range decoy designed not to destroy enemy targets, but to confuse enemy defensive weapons and to aid the penetration of bombers on target missions. It is mounted on special racks in the bomb bay of the B–52, and when launched produces a blip on enemy radar screens similar to the image given by the B–52 Stratofortress. The Quail flies in different paths but at the same speed as the B–52. Around the body of the Quail are small fins that lie in folded position until the decoy is moved into launching posture. This space-saving feature makes room for the decoys without interfering with other weapons carried by the Stratofortress.

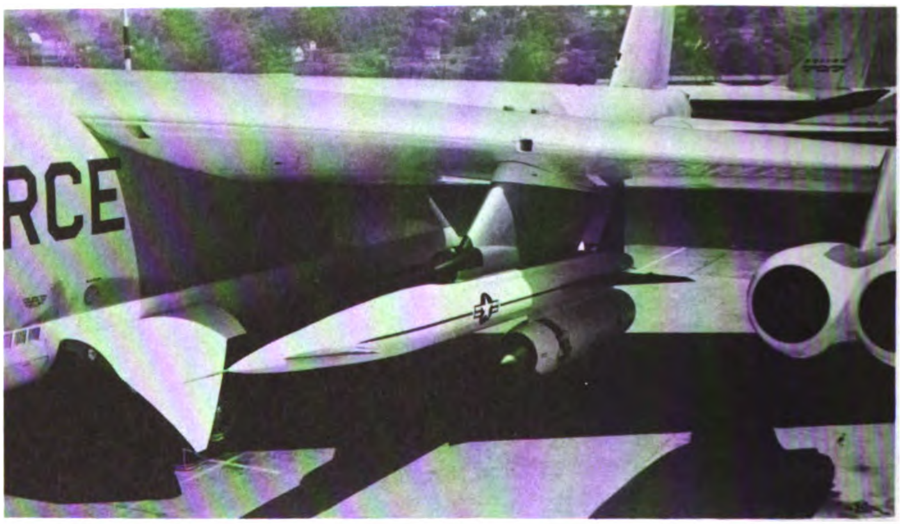


FIGURE 110. The GAM–77 Hound Dog is shown under the wing of a B–52G bomber.

GAM–77 Hound Dog.—A new missile put together out of the parts and pieces of old projects, and thus aptly named the Hound Dog, began entering the inventory in 1960. This missile gave SAC true global mobility and flexibility—the capability to launch attacks while still 500 miles from the target. This supersonic missile can be used against defense centers to aid the bomber's penetration to target. Each air-launched GAM–77 Hound Dog missile adds a 1-megaton hydrogen punch and an extra reach that combines to make a single B–52 the mightiest weapon ever seen (Fig. 110).

GAM–87A Skybolt.—Another air-launched ballistic missile (ALBM), the GAM–87A Skybolt, is designed to travel many times the speed of sound with a range of approximately 1,000 miles. The Skybolt was intentionally devised to utilize existing equipment, such as the B–47, B–52, and B–58. Only a relatively easy modification of the bombers and ground checkout devices is required. The air-launched ballistic missile is a major contribution to SAC's deterrent power. Long-range air-to-surface missiles, such as the Hound Dog and the Skybolt, give SAC's bomber force added strength and provide the United States with the most mobile striking power ever achieved.

OPERATIONS

Command Post

The Strategic Air Command's underground command post at Offutt Air Force Base, Nebr., includes a communications center, a global weather center, a world-spanning communications system, and a special long-distance telephone system connecting the center to each SAC base throughout the world.

Primary Alerting System.—The primary alerting system, keyed by the famous Red Telephone, enables controllers on duty round-the-clock in the command post to relay a launch order to every SAC base throughout the world within moments after attack warning is received. The previous alerting system, which operated on a dial procedure, required approximately 35 seconds to activate and reached only bases in the United States. With the new primary system, the controller can achieve instantaneous contact with all SAC command posts around the globe simply by lifting the phone, a procedure which saves precious seconds.

A secondary alerting system is ready for immediate use in the event that the primary system is destroyed or suffers mechanical failure. With the secondary system, the controller can contact SAC command posts through alternate routing points in the numbered air forces.

Operations Control Room.—In the large operations control room, wall-length panels, four rows deep, contain data on SAC's striking force, current command operations, and latest weather observations. The panels, which are mounted on trolley rails, reflect all information needed to direct the global force in peace or war—world maps 16 feet across, latest weather conditions, charts showing deployment of the force, operational status of aircraft and missiles, current training exercises, and so on. SAC's emergency war plan, which

is constantly changed as new information becomes known, is maintained on panels which can be quickly uncovered and placed in immediate use.

Adjoining the operations control room is the operations plans room, where skilled planners, weighing all available information, write orders that direct attacks against enemy targets.

INTELLIGENCE ROOM.—Also adjoining the operations control room is the intelligence air room, where information about fresh war plans is compiled and posted. The intelligence agency prepares the target materials for the bomber crews to study in order to find and destroy the assigned target. Thorough research is performed in all intelligence areas to compile the most up-to-date information available and to insure that both bomber and missile crews have the most accurate and reliable maps and charts. Reconnaissance technical units screen and collate all the source material and reduce the data to the finished product which is presented to crew members who have the ultimate job of penetrating to the assigned objective.

When the target assignments and related materials reach the bomb wings, the information is immediately presented to the crewmembers. Daily intelligence briefings, continuous target study, and the intelligence contained in combat mission folders—all information compiled by the intelligence agency at headquarters—provide the bomber crewmembers with all the necessary intelligence information needed to perform their mission.

Detailed order of battle data on the enemy's fighter and radar defenses are furnished each crewmember for thorough study. In addition, estimates of the enemy's capability in air defense are made by the intelligence personnel and are disseminated regularly to SAC bomber crews. Fighters, radar, missiles, and flak—all the forms of defense at the enemy's disposal—are constantly under study at the headquarters. The results of these studies are immediately dispatched to the bomb wings on the most timely basis.

The intelligence program is also concerned with material and training that will help aircrews survive or return safely if they are forced to eject or crash-land in unfriendly territory. Intelligence briefings are provided for each mission to assist crews in the preparation of a planned course of action in the event they must abandon the aircraft over enemy territory.

TRAJECTORY CENTER.—The intelligence staff also plays a big part in targeting. The T (for trajectory) men consist of mathematicians, computer programers, and technicians. These men calculate complex trajectories for missile units in the field. Using information compiled and processed by SAC's global intelligence system, programers establish missile trajectory control factors and maintain them on a current basis as target data and priorities change.

COMPUTER ROOM.—The computer room houses the electronically stored information pertaining to the SAC forces. A worldwide electronic combat-control system, identified as the 465–L, enables SAC units to feed continuous information on movement and status of weapon systems, aircraft, bases, and personnel directly into computers at SAC headquarters. At the headquarters, the information is used to provide instantaneous and up-to-the-minute displays

or stored for future reference. The 465–L, with a far greater speed and storage capability than the old IBM 704 system, can provide the command with a rapid and highly flexible aid for maintaining effective control of its global operations. The new system can also give SAC a greatly improved capability, resulting in decisions based on more reliable data which are furnished in a more refined form.

GLOBAL WEATHER CENTRAL.—The world's biggest weather facility, Global Weather Central, is also located in the underground command post. In this center, operated by the 3d Weather Wing, weather information of vital concern to the control of the SAC force in peace and war is gathered, analyzed, and plotted. Forecasts are made and then constantly reevaluated and confirmed or revised through current weather reports received from stations all over the world. These forecasts provide the latest weather data for SAC's global force twice daily.

In addition to providing worldwide forecasts, Global Weather Central monitors all critical SAC flights and plots all units on charts to insure that all SAC operations have sufficient warning against sudden weather changes.

Global Weather Central is connected with each SAC base by means of the Nation's first high-speed facsimile network. Linking 57 weather stations at Air Force bases throughout the United States, the hookup allows weather maps to be transmitted simultaneously, commandwide. Likewise, forecast revisions and special weather warnings can be disseminated in an instant.

CLOSED-CIRCUIT TELEVISION.—Another unusual feature of the command post is a closed-circuit television system. Color television cameras are installed in the main command post, the intelligence air room, and the global weather center. Receivers are located in the offices of the commander in chief and key staff members. The system permits instant briefing of top staff officers, and thus eliminates the need for them to go to the several display rooms to gather information required for immediate decision.

The command post is also connected by closed-circuit television to the North American Defense Command Combat Operations Center at Colorado Springs, Colo. Immediate transmission of combat data over this system permits the quickest possible warning of enemy attack and allows instant coordination of our offensive and defensive aircraft movements.

Stationed at the Colorado Springs center is a team of SAC officers headed by an experienced controller. In the event of war, this team would be in constant visual contact with the SAC command post through the television hookup and would aid in coordination of SAC and Air Defense Command activities.

The color television circuit is also capable of being hooked up with Headquarters USAF in Washington, D.C.

AIRBORNE COMMAND POST.—In May 1960 the Strategic Air Command announced its plans to send aloft aerial command posts to avoid the possibility of a knockout blow on its headquarters from enemy missiles or planes. Three converted KC–135 jet tankers, equipped with advanced radio facilities, make it possible for a senior officer aboard to keep in touch with the Joint Chiefs of Staff,

bases, and other aircraft. The flying command stations can assume key functions of the underground command post.

Combat Training

The statement that "everything SAC does begins and ends with targets" has often been made in reference to SAC's operations. The optimum in strategic destruction of the enemy potential to make war is the guideline for all command post operations and combat training. Training is directed toward the successful accomplishment of SAC's wartime mission: to hit the predesignated enemy targets if the aggressor forces us to release our unbelievably strong destructive power.

CREW TRAINING.—At this very moment there is a SAC bomber somewhere in the free world flying a simulated combat mission. Although members of this combat crew are well aware that they are flying over friendly territory, they know that the nature of their mission is essential and mandatory to the survival of the free world. Each man in each crew has been trained so that in event of war, he can evade the enemy defenses, seek out and bomb the target, and safely return to his home base.

SAC crewmembers are carefully trained and matched. Each individual airman has first received his basic training, then his specialized schooling, before he becomes a part of a SAC crew. Likewise, the jet pilots and observers have become qualified in their respective fields before they are assigned to a crew. After matching, the crews receive several hard months of proficiency training and are then upgraded to combat-ready status. Constant training and frequent returns to the classroom keep crews current and proficient.

Unit Simulated Combat Missions (USCM's) are scheduled regularly in order to evaluate a unit's capability to perform its assigned mission. Normally, two USCM's will be accomplished by each unit during each fiscal year. Additional numbered air force USCM's are executed on a no-notice basis. Such continuous evaluation keeps SAC's crews combat ready.

Wartime conditions are simulated in long painstaking flights day and night in all sorts of weather throughout the world. The only difference from real combat missions is that gun cameras are used in all aircraft instead of bullets. To test the mettle of the crew during the flights, unusual conditions, such as simulated engine fires and failures, cabin fires, etc., are experienced. The crews must develop teamwork to meet all eventualities. They must be capable of precision bombing because enemy targets are often located in densely populated areas, and every effort must be made to avoid killing people unnecessarily. Precision navigation is also a necessity because crews in actual combat would fly over strange territories, oceans, and polar regions. The crew must not fail to destroy the assigned practice target, for their actual target in combat might be an enemy airfield that, if missed, would provide the aircraft to destroy targets in this country.

Continuous routine training missions keep SAC's crews in a state of readiness to launch a counterattack at a moment's notice. Radar bomb scoring, one tech-

nique that is used, permits crews to receive realistic training in the use of radar bombing against industrial targets. B–47 and B–52 navigator-bombardiers receive practice in recognizing cities, factories, buildings, and other structures as they appear on their radarscopes. Twenty-one widely scattered cities throughout the Nation are theoretically bombed dozens of times daily by SAC jet bombers. These cities are the location of SAC's Radar Bomb Scoring (RBS) sites. Using a combination of radio and radar contact between aircraft and RBS sites, the command can actually score the bombing effectiveness of each of its combat crews without a single bomb being dropped.

The bombers, flying as high as 45,000 feet, make their practice bomb runs on their target cities, keeping in constant touch with the RBS site. The RBS radars "lock on" the oncoming bomber and track it automatically on a plotting board. Just before the simulated release of the bomb, the aircraft transmits a tone to the RBS site by radio. The aircraft then indicates its point of simulated bomb release by stopping the tone; this action in turn causes the tracking mechanism to stop. The target and the radar site have been precisely plotted on the tracking board by this action. By using figures on distance and direction of the bomber from its target, the aircraft's groundspeed, heading and altitude, wind conditions, bombfall characteristics, and other data, RBS technicians can compute the accuracy of the particular bombing mission. Utilizing radar bomb scoring, SAC crews can obtain invaluable realistic training in bombing day and night and in all kinds of weather.

To test the accuracy of its long-range bombardment crews and equipment, Strategic Air Command introduced in 1948 the first annual Bombing-Navigation Competition. Except for 1950 when the Korean war began, the meet has since taken place each year. Each competing aircraft flies a mission of some 2,700 miles over a prescribed route to bomb three widely separated target cities, and, guided only by the stars, flies a 2-hour navigation leg. The aiming point of the navigator is not just a city: it is a specific building in the city, and perhaps the corner of that building. Accuracy of simulated bomb drops is measured in feet. Exact impact points of the simulated bombs and the plane's precise position as it ends the navigational leg are computed by an intricate system of electronics and radio signals. An umpire flies with each crew to monitor their operations and to insure strict compliance with competition rules. In 1959, appearing for the first time were air refueling crews and their KC–97 and KC–135 jet tankers, so that the "world series of bombing," as it has been tagged, became a bombing, navigation, and air-refueling competition.

Another training operation, nicknamed "Operation Oil Burner," was designed as a gigantic practice in penetrating potential enemy defenses from low altitudes. Because it is almost next to impossible for the radar of a potential enemy to detect airplanes approaching at low levels, the B–52 and B–47 jet bombers frequently practice low-level bombing techniques. Under this flying operation, the aircraft fly at approximately 300 miles per hour at altitudes of at least 1,000 feet above the highest point on their routes, which have been approved by the Federal Aviation Agency. Missions are flown in all kinds of weather, day or night. Each

of the low-level corridors makes use of an RBS site where every technician in the RBS detachment understands the urgent requirement of positive accuracy in scoring. The technicians complete their scoring in a matter of minutes and transmit the score to the bomber before it leaves the range. It might be noted that the airplanes on these missions carry neither nuclear nor conventional weapons.

Another training technique is the use of flight simulators, exact reproductions of aircraft cockpits, which never leave the ground but put the pilots and crews through realistic simulated flights. The three types of simulators used—the KC–135, B–52, and B–47—are intricate electronic machines. Through miles of wiring, innumerable electronic tubes, and a sound recording system, the simulators put a pilot to every test he might encounter in actual flight, right down to a nerve-tingling crash—all without casualties or damage to a real aircraft.

During simulated flight there is no actual movement of the simulator, but a built-in sound system faithfully reproduces flight noises. Even plane vibration, as cockpit instruments show speed near the sound barrier, can be felt by crews. The simulators can reproduce as many as 65 malfunctions of aircraft and equipment. For example, a pilot may suddenly find the wings of the craft heavy with ice, or he may experience the dangers of aileron reversal, the sometimes fatal tendency of controls to reverse their effects at high speeds. The intricate machines can simulate loss of one or more engines, landing gears which cannot be raised or lowered, and many other in-flight hazards, including weather conditions ranging from sunshine to rainstorm to typhoon.

During the simulated flight, a radio operator fulfills the role of ground facilities which would be contacted on real flights. The flight course is charted by an electronic recorder, and every course deviation is automatically traced on full-scale aeronautical charts.

At any moment during wartime, a SAC crewmember might be forced to bail out over enemy territory. For this reason regulations require each combat crew to complete courses in physical conditioning and combative measures, as well as survival training. During the course in combative measures, the student gains a variety of skills in such combative arts as judo, wrestling, and police fighting. He knows which of these techniques will be the most effective in any given situation, and he has the will to fight when he sees that his chances are good. The crew member is instructed in methods of escape from jails, concentration camps, and prison compounds. He is also trained in the basic methods of survival under almost every known condition on earth—the jungle, the frozen North, the desert, and the ocean. He learns that virtually everything that moves can be eaten, even all reptiles except the toad. He learns how his parachute can be used for a tent, a knapsack, or a fishnet; he learns how to survive on little water. SAC men have learned that the survival training courses may be tough, but they also realize that the myriad things learned are, in a sense, their own insurance against emergencies that might occur.

AIR REFUELING.—Air refueling operations are another vital phase of the combat readiness program. Air refueling operations have extended the range

of the jet bomber force and have enabled it to fly nonstop against any target in the world. Training in this important phase of SAC's operation goes on continuously. In fact, SAC refueling missions are conducted 24 hours a day throughout the world. Jet-to-jet refueling (jet tanker to jet bomber) means that the medium (B–47) and the heavy (B–52) bombers can take on a full load of fuel without slowing down, changing course, or descending from their most efficient altitudes. The time saved means the strike force can reach an enemy quicker. The fuel saved means more air-miles per gallon of fuel transferred. Today the sweptwing jet bombers and fuel-laden tankers are completing an aerial hookup somewhere in the world every 3 minutes (Fig. 111).

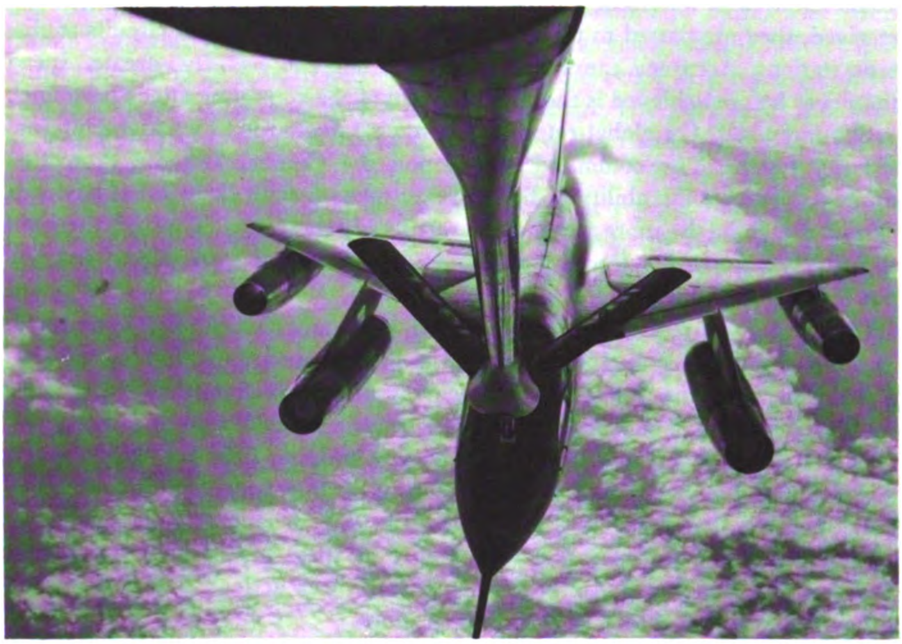


FIGURE 111. A B–58 moves into position for refueling from a KC–135 tanker.

MAINTENANCE PROGRAM.—One of SAC's most important, but often unpublicized, operations is the maintenance program. The crews who fly the planes are backed up by the men in fatigues who keep the planes ready to fly. Many months of class instruction and on-the-job training go into tailoring aptitudes and skills to the aircraft. Modern weapon systems, such as the B–52G with the Hound Dog, are not simple. Much time and effort are spent daily to keep maintenance crews current in all aircraft standard procedures and modifications. Policy modifications have reduced aircraft accidents to the point where the SAC rate is among the lowest in the Air Force. Without the well-maintained aircraft and missiles, the command would be unable to keep our powerful deterrent force alive.

COMMUNICATIONS.—Another portion of SAC's operation which often goes relatively unnoticed is the communications program. SAC officers and airmen daily operate networks of almost 750,000 circuit-miles; they use cable and radio for transmission of voice, teletype, television, and other forms of communication. SAC airmen throughout the world prepare, transmit, and receive teletype messages every day; they record the transmission time for each message and constantly strive to reduce handling time. Periodically, they exercise their ability to the utmost through Command Post Exercises, or CPX's as they are better known. These exercises simulate war conditions.

At the start, and often without warning, the officers and airmen of the SAC teletype network swing into 12-hour shifts—many men work 18 or more hours a day and maintain this pace for days on end. As fast as messages are received, they are passed to the addressees, or relayed over other circuits to distant stations. Accuracy cannot be sacrificed, nor can security; greater speed than ever before achieved is the common goal of the communications personnel.

SECURITY.—SAC's global retaliatory force is safeguarded by a tight internal security system. The command relies upon the Combat Defense Protection Force to preserve the ability of the crews to take off with their lethal payloads despite attack or the more treacherous thrusts of saboteurs. Through the tight security system, SAC's forces, its aircraft, and its missiles are ready and will not be caught off guard.

OTHER SUPPORT.—Because of the hard work and dedication of thousands of other support personnel, such as those in the airbase groups, combat aircrews and missile crews are able to devote their duty hours solely to the vital training that insures they will be ready for combat whenever needed.

MISSILE TRAINING.—A comparatively new training field for the Strategic Air Command is the training of missilemen in the operation of intercontinental and intermediate range ballistic missiles. In 1957, when SAC was given the responsibility for the operational capability of these missiles, the 1st Missile Division at Vandenberg Air Force Base, Calif., was activated to control ballistic missiles designed for strategic air operations.

The primary mission of the 1st Missile Division was to train units to become operationally ready. However, one operational-type Atlas squadron is assigned to Vandenberg under the direct control of the 1st Missile Division. One strategic missile squadron handles the SM–65 Atlas training for the entire command, and also maintains the combat-ready status of the Atlas battery there. A second squadron of the 1st Missile Division was activated to train crews for the other long-range missile, the SM–68 Titan. This squadron was also to have an operational combat capability. A third squadron is responsible for training crews in the intermediate range ballistic missile, the SM–75 Thor. The training of missile crews for the other intermediate range missile, the SM–78 Jupiter, is conducted by the Army in Huntsville, Ala.

Thor missile training is primarily for RAF personnel, although some USAF personnel go through the Thor program to provide instructor replacements and to serve with Thor units in England. The Thor squadron provides preopera-

tional training, or integrated weapon system training, to personnel who have first gone through individual training with the contractor. These specialists in individual missile systems, such as hydraulics and electronics, are then welded into a team. During the 8-week program a launch crew goes through a total of 12 countdowns before it is considered fully trained. SAC-type standardization checks are given launch crews much in the same way as standardization checks are given bomber flight crews. Continuous training is provided for Thor crews. Twice each year they return to Vandenberg to participate in the Combat Crew Training Launch program, a refresher training and updating program.

The Atlas training course, which lasts 12 weeks, is set up for students who have, like the Thor students, received individual training with contractors at the manufacturing facilities or at Air Training Command bases. The Atlas training program has a dual role: to develop the emergency war operation capability (the firing of Atlas deterrent weapons in the event of a national emergency) along with the operational training program. The purpose of the operational training program is to form a cadre of instructor personnel and to develop operational crews for future Atlas sites.

After each ICBM unit has demonstrated that it is operationally ready, it is integrated with bomb units of numbered air forces in the United States. When the IRBM units are determined to be combat ready, they are deployed overseas.

Crew training for the operation of other strategic missiles, such as the Minuteman and Hound Dog, is scheduled in accordance with the predicted operational availability of the missiles.

Management Control.—Combat readiness is of the utmost importance in the Strategic Air Command. In order to measure its combat capability, the command established a management control system. Monthly management control statements present an up-to-date composite picture of the command's readiness to strike. The report shows the results of practice bombing missions, training programs, and other important items contributing to combat capability.

Each month the management control system scores every unit in the command on performance. Scores are worked out on the basis of past performance and reported under general headings such as operations, personnel, materiel, and special missions. A compilation of the scores indicates SAC's status and points up deficiencies to be corrected. Through this means the command insures its combat readiness.

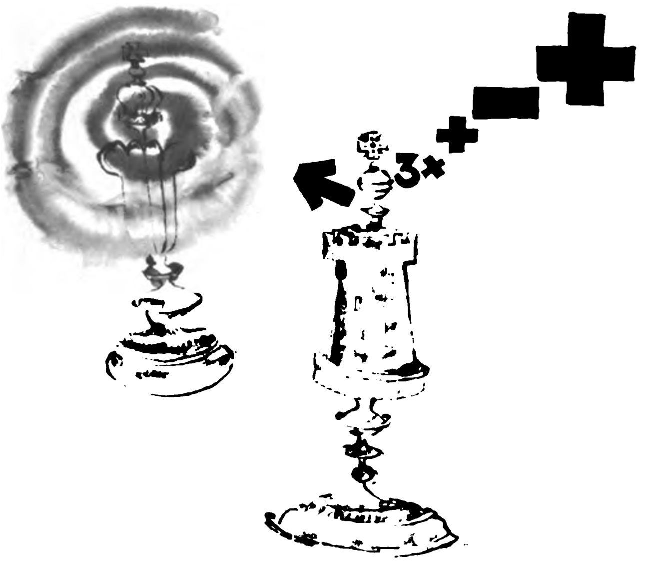
It is obvious that through its command post operations, its continuous combat training program, and its constant checking and measuring of its combat status and readiness, the Strategic Air Command is poised for action. In the words of General Power, "We have constructed a force of overwhelming strength and flexibility—a force which stands between continued peace and the threat of a nuclear holocaust."

Disaster Control.—In addition to being combat ready, SAC must also be ready to cope with incidents involving nuclear weapons. For this reason

FIGURE 112. A Thor missile rises from its launch pad.

the command established its disaster control program. At SAC bases throughout the world, disaster control teams are prepared to minimize the effect of a nuclear disaster on the immediate operational capability of the strike force and to restore the operational capability of the base or unit affected as soon as possible following an attack or incident.

The disaster control operation consists of three phases: discovery and notification, containment, and cleanup and recovery. The first phase includes verifying the initial disaster report, alerting designated agencies, activating disaster control teams, and notifying higher headquarters. The second phase includes such emergency actions as securing the disaster area, evacuating nonessential personnel, rescuing and providing medical treatment for casualties, preventing further personnel or facility damage caused by detonation of explosives, and assessing possible immediate radiation or other toxic hazards. The cleanup and recovery phase of the operation includes recovering components of weapon systems, removing debris, repairing damaged facilities, and collecting and analyzing environmental samples to detect radiation. The disaster control teams stand ready to safeguard not only SAC's bases but also U.S. cities and towns against potential hazards associated with accidents involving nuclear weapons. Thus, it is apparent that SAC's disaster control program affords us another protective measure in this nuclear age.



CHAPTER 12

TACTICAL OPERATIONS

Now that aerospace power and its flexible means of delivery through tactical units is part of the U.S. arsenal, this Nation and all nations of the world have a greater chance of fulfilling their desire for peace than at any other time. For some years now the United States has held the Soviets at bay in good part through the massive striking power of SAC, as explained in the preceding chapter. All during this time the Nation has contended with the strong possibility of fighting a war limited in scale and area, but still at a great cost. Now,

◀ A fighter comes in firing its load of rockets at a simulated tactical target.

the Communists can be restrained in these small wars, as well as in a general war.

The threat still remains, however. Throughout the Middle East there is unrest. There are ample indications that the Soviets have keen interest in these areas. But here again, the Soviets will probably not promise open military aid to the nation they are backing unless, of course, they plan to initiate a general war. In any eventuality the decision to fight rests with them.

Sudden deployment of the Tactical Air Command's numerically small but potent composite air strike forces to a sensitive area probably would not prompt the Soviets to launch a global war. They are not likely to risk such a war while faced with immediate retaliation by SAC.

Two checkmates, then, have been placed before the Communists. A general war has been effectively deterred by strategic aerospace power, and now limited wars have an equally effective deterrent in tactical aerospace units.

POTENTIALITIES OF TACTICAL AEROSPACE UNITS

Ultimately, the preparation and state of readiness of individuals and units to participate in tactical operations is the responsibility of the Tactical Air Command (TAC), although the employment of the tactical instruments will probably be the responsibility of other commands. Tactical forces are largely found in TAC and the two major overseas air commands, U.S. Air Forces in Europe (USAFE) and Pacific Air Forces (PACAF), although one should not be surprised to find tactical aerospace units anywhere in the world. Modern warfare demands the ultimate in flexibility and mobility. In effect, modern tactical aerospace units are the counterparts of the Roman field armies, which were centrally located in strategic positions from which they could dispatch units to any portion of the frontier that was under attack at a given moment and there be utilized by the local commander.

The tactical aerospace forces are truly a mixed force: they use the various versions of the fighter class aircraft, specially adapted bombers, cargo aircraft, helicopters, rockets, guided missiles, machine guns, high-explosive and incendiary bombs, and, of course, nuclear weapons. Tactical units are capable of being used in support of both strategic and defensive operations as the need dictates.

The potential of tactical aerospace forces was best described by Gen. Thomas D. White when he said:

> . . . our tactical air forces with enormous firepower, global mobility, operational flexibility and versatility, have become a deterrent to aggression and a decisive force in war. As such, our Tactical Air Command assumes a place alongside our Strategic Air Command as a potent force for peace.

The mobility and flexibility of tactical air forces of which General White spoke encompass these things: ability to provide defense and assistance to the U.S. Army and naval forces in any type of war; the ability to support all military forces of smaller friendly nations in the event of aggression; the ability of tactical air forces to sustain independent operations in remote areas of the

globe with very little support and in absence of ground and sea forces; and a nuclear capability of destroying any target within tactical range, thus allowing Strategic Air Command to concentrate most of its efforts against the most vital, select targets deep in the enemy heartland in the event of a general war.

Thus we can see that tactical aerospace forces provide the power, mobility, and flexibility to deal with any situation that may present itself. (Fig. 113.)

FIGURE 113. Troop carrier C–124 loads army paratroops and equipment for a practice tactical air drop.

TAC represents the true expression of versatility in aerospace power. In contrast to SAC and ADC, which have a mission oriented toward a single objective, TAC has a mission which is varied and complex. It might be termed the Air Force's Jack-of-all-trades. Because tactical aerospace units are especially trained and equipped to be versatile, they are prepared to fight in a general war, a limited war, or a cold war.

In a general war, which today represents the most serious threat to our security, tactical aerospace forces would team up with SAC and allied strike forces. These tactical forces—nuclear-capable, combat-ready and positioned overseas—greatly complicate the problem of launching a successful surprise attack against the free world. If the enemy were to launch a surprise attack, TAC forces in the United States would be immediately dispatched overseas to fill up the gaps in U.S. theater forces created by the enemy's initial air offensive.

At the same time, TAC fighters in the zone of interior would be prepared to supplement ADC interceptors and missiles in defending North America against enemy air attack. TAC's capabilities in this air defense role have been repeatedly tested in joint TAC–ADC exercises.

Of all the air commands, TAC is the one best qualified to cope with the more insidious and more probable limited war. Tactical forces can deliver nuclear weapons and a wide range of high-explosive weapons. Also as a result of its long-term traditional relationship with the Army and Navy, TAC is equipped and trained to fight in close relationship with United States or allied surface forces.

TAC's capability for fighting a limited war is made possible through the use of the composite air strike force (CASF). This is a versatile, highly mobile, self-sustaining package of air power which can be dispatched from the United States and arrive in a matter of hours at any area in the world where a show of force or an application of force is required. It can be tailored to meet any situation.

Since operations of the type that would be conducted in cooperation with ADC and SAC in a total, or general war, are described in previous chapters, this chapter concentrates attention on tactical operations employed in a limited rather than a general war. It also describes some of the tasks that tactical aerospace forces perform in the cold war.

TACTICAL OPERATIONS IN A LIMITED WAR

Definition and Nature of a Limited War

Wars may be kept limited in a great many ways. All wars are restricted in point of time. They may be limited as to area, size of forces, weapons used, and types of targets. Any number of definitions of limited war can be found, some incompatible with others but each one usually designed to suit the purpose of the author. For the purposes of this text, limited or restricted war is considered to be a conflict in which the nations involved employ overt firepower and in which one or more of the belligerents, tacitly or formally, establish limiting conditions designed to forestall a condition of total war. This definition incorporates the idea that limited war is military action short of an all-out nuclear exchange between the free world and the Communist nations. It also connotes a war of limited forces and, therefore, not a war that would place an intolerable burden upon our society, as in the destruction of great segments of our manpower or the laying waste of our industry. It also provides for any degree of limitation of forces or weapons and includes the various types of limited war that are commonly referred to as "guerrilla action," "police action," "local wars," "brushfire wars," "small wars," "restricted wars," and "peripheral wars."

Whatever the accepted definition of restricted war, it must be remembered that such a war may appear total to either side if survival as a sovereign nation is at stake. The border line between restricted and total war in this instance will

rest on the capability of the nation facing total threat to apply unilaterally, or with allies, similar or more stringent conditions on the other belligerent.

Once a limited war has been started, it must be kept from growing into a total war. How may wars be kept limited? One prime consideration is to keep the strategic strike capability of the United States and Russia immune from attack. Further, any penetration near the boundary of either country is likely to be interpreted as an approaching attack. Should either side threaten or attack the long-range air force of the other, then the objectives would become enlarged and the war would become total.

Many people believe that wars cannot be kept from expanding if nuclear weapons are employed. They feel that because of the dynamic nature of warfare, in which each participant strives to gain the advantage, it is too much to hope that the enemy would stop short of total war once nuclear weapons are introduced. The United States cannot and does not indorse this line of thinking. We believe that we must employ aerospace power in such a manner that it can be brought to bear immediately in whatever strength and against whatever targets may be necessary to make further overt actions completely unprofitable to an aggressor. This, of course, is not intended to imply that nuclear weapons must or should be used in any and all types of limited wars. They should be used only when conditions favor their use. Admittedly, there is danger in that if nuclear weapons are used in limited war, the competition to gain advantage could lead step by step to total war. There are certain courses of action, however, that can keep wars limited.

First, it is essential that we maintain a capability to win a total war, and there should be no doubt in the minds of the Communist leaders that we have this capability. So long as this is established and so long as an enemy is convinced of our determination to use this force, if necessary, he will have to realize that his objectives cannot be acheived through increasing the scope of any war.

Another way to keep aggression limited is to take immediate action with sufficient speed and power to achieve stabilization of the military situation at the earliest possible time. This requires that we be capable of global mobility—rapid movement of the necessary force to any place on the globe.

Realistic and reasonable political objectives are essential if limitations to specific wars are to be maintained. Since war objectives are basically political in nature, political objectives in a large measure determine the degree of limitations that belligerents are willing to accept. The objectives are determined by the belligerents. They may be unconditional surrender, the prevention of complete defeat, or the dragging out of the war until the enemy is willing to negotiate or compromise some of his objectives. Or again, the objectives may be to keep an ally of the enemy from entering the conflict or to prevent the expansion of the latter's influence. Or else the objective may be flexible and may change during the course of the war, as in Korea, where our objectives changed from that of forcing the North Koreans back to their own boundaries to that of unification of all Korea.

In view of lessons of the past and the preponderant role of political objectives

in determining the scope of war, our aims should be limited if we wish to keep a war from expanding. If too much is demanded from an enemy, he may be inclined to fight with all the means at his disposal.

Basic Tactical Tasks

Aerospace power is a real deterrent to the initiation of a limited war, but in the event that the enemy begins such a war anyway, air forces can be employed in a variety of tasks. Employment may vary from attacks on airbases and logistic systems to direct attack on military forces. It may involve a series of graduated deterrents, that is, the application of a series of attacks of gradually increasing intensity that would be decisive. Depending upon the results we expect from an attack, we can exercise flexibility in our choice of targets, weapons, and the circumstances under which we launch an attack. That is, our employment of weapons and our application of firepower must be flexible and discriminating. In effect, this is selective retaliation. The firepower should be consistent with our objectives. Furthermore, we should be able to vary the intensity of the war so as to allow diplomatic negotiations, should these be feasible.

All forces are employed in a limited war with the objective of persuading the enemy; denying a place, facility, or service to him; or destroying or neutralizing the enemy if he refuses to comply. Attention is centered here on the three basic tasks that tactical air forces perform in limited war: gaining control of the aerospace, interdiction, and close support.

Control of the Aerospace.—To gain and maintain an acceptable degree of control of the aerospace is foremost among the tasks. If this is not done, the

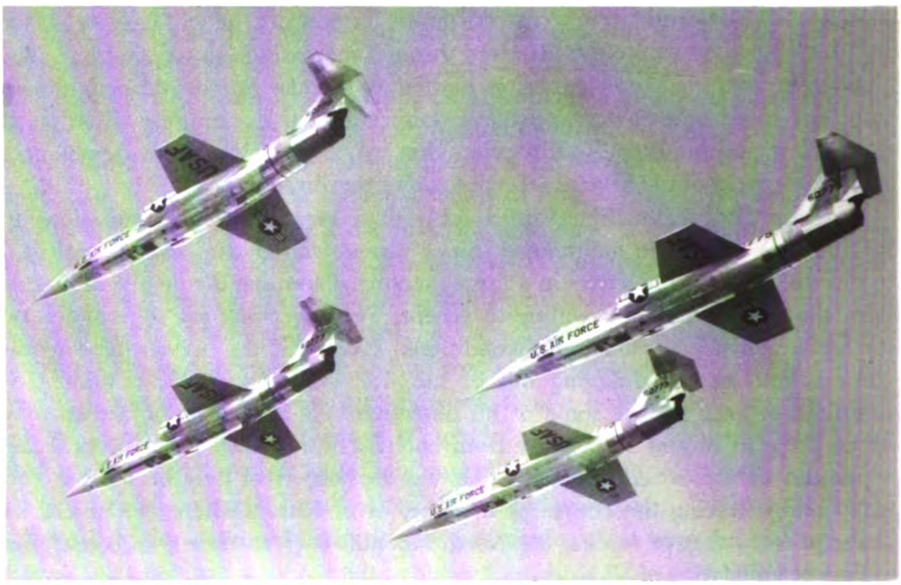


Figure 114. Air Force F–104's.

remaining tasks become impossible to achieve. If the enemy has free play in the aerospace, our forces face annihilation. Our forces are subject to continued attack, and much effort must be expended in operations of a defensive type—effort less productive than offensive employment. Superiority within the area affected by a war is a prerequisite to extensive ground action if such action is also needed.

Aerospace superiority in a given area at a given time may be difficult to achieve. For example, if we should fight a limited war with Red China, we would find it difficult to achieve aerospace superiority because the source of Red China's strength is the Soviet aircraft industry. The principles for employing forces in a counter-aerospace role would dictate that we strike the source of the enemy's aerospace power, but reason would rule out this course of action. It is logical to assume that a minimum condition for limiting a war would be the immunity of the United States and the U.S.S.R. from attack. Thus aerospace superiority over the combat zone would be increasingly difficult when the combat zone is near the Soviet periphery. Aircraft based within the U.S.S.R. would be immune to attack except when over the battle areas implicated. Furthermore, penetrations near the Soviet boundary would probably be interpreted as an approaching attack on the U.S.S.R. Any penetrations near the United States or Canadian boundaries could cause us to launch SAC forces. In limited war, then, our application of the principles of employment may be less than optimum because of restrictions imposed by political objectives.

INTERDICTION.—Interdiction should be a selective campaign waged by aerospace forces against the enemy's total logistic organization involved in a limited war. The cumulative effects of such a campaign would result in disorganization and neutralization of the enemy.

An effective interdiction campaign can, in time, neutralize enemy ground forces. In terms of weapons, weapon systems, and effort expended, interdiction of selected battle areas is the most remunerative operation for aerospace forces in furthering operations of surface forces. This action prevents the enemy from massing troops, equipment, and supplies. In addition, it limits significant moves into, out of, or within the area and disrupts enemy communications.

Interdiction is not simple to achieve. Actually there is no real means of preventing an enemy from obtaining all supplies and reinforcements. This is neither necessary nor the ultimate purpose of interdiction. Interdiction is effective whenever the amount of logistic support received by deployed forces is reduced to the point that the supplies flowing in are less than those consumed and there is no longer a reserve. For an interdiction campaign to be successful the land forces must engage the enemy in sufficiently large-scale operations to force him to use all available supplies. During the armistice negotiations in Korea our ground forces did not conduct a successful interdiction campaign because they were operating under a policy of limited offensive actions. Using traditional strategy and tactics, our forces pursued the course of action that gave promise of minimizing its casualties. This action permitted the enemy to control his consumption rate by controlling the intensity of ground operations.

An interdiction campaign could involve more than the battle zone. In gaining and maintaining command of the aerospace and in achieving large-scale interdiction and attrition theaterwide, the interdiction campaign would affect more than the land battle. For example, during World War II our interdiction campaign against the German forces in North Africa included more than the battle zone. Air actions were carried on almost continuously against supply and communications targets near the battle zone. While these actions intensified as major battles were developing, the air forces were, on the whole, engaged in a widespread campaign of attrition against the enemy's entire organization and structure for fighting in that theater.

Although gaining control of the aerospace and interdiction are often regarded as separate and distinct tasks, it is sometimes difficult to separate them. In a widespread campaign of attrition, as in North Africa, individual attacks and operations are as much a part of one task as of the other.

CLOSE SUPPORT.—Close support includes those activities that are employed in direct support of the surface forces. It assists them in accomplishing their immediate task, which is to close with and defeat enemy forces. Aerospace missions in close support of ground forces elements must, of course, be closely integrated with their fire and movement. To employ forces properly in joint air-ground operations, a highly developed and systematized control and communications system was developed, which makes coordinated control and action possible and is the key to exploiting the inherent flexibility of our forces.

Priority of Basic Tasks

The capability of aerospace forces to accomplish any one task depends upon the priority assigned to that task as compared with others. This priority cannot be prescribed by arbitrary procedures, but must be based on assigning precedence to these tasks in the order of their importance in controlling the enemy's threats. In this nuclear era it is obvious that extensive surface operations are not possible until control of the aerospace has been secured. Therefore, the counteraerospace task is paramount. In a limited war, aerospace superiority is relative, not absolute, since forces operating from beyond the delimited battle area can strongly influence the battle. Under these circumstances superiority must be reestablished whenever necessary.

Ordinarily the forces engaged in limited war must first attain aerospace superiority in the area of engagement and secure the limited war areas against any buildup or deployment of enemy ground or naval forces. Meanwhile, the strategic striking forces are employed to keep the war from expanding or to deliver decisive blows to critical targets.

OTHER TASKS OF TACTICAL AEROSPACE FORCES

There are two other tasks which are also inherent in the basic missions of tactical aerospace forces just described. These are tactical reconnaissance and airlift.

The need for tactical reconnaissance is an obvious one. The subject has been discussed previously in Chapter 8, "Target Intelligence."

Tactical airlift encompasses two broad areas: airlift of personnel and materiel indigenous to a tactical air operation (e.g., in support of the movement of a composite air strike force), and support of U.S. Army operations. (Fig. 115.)

FIGURE 115. An L–37 light tank weighing nearly 27 tons rolls from a MATS C–124.

Although major air movements of troops and materiel would normally be provided by the Military Air Transport Service (MATS), movements within a relatively small area are carried out by tactical air transport units, such as the 322d Air Division in France or the 315th Air Division in Japan. Their tasks might consist entirely of airlifting an infantry unit from one area to another, transporting a paratroop unit to a drop area, or making a paradrop of emergency supplies to an isolated ground force detachment.

Further, in combatting the Communist influences in the cold war and in preventing a limited war, tactical aerospace units have played an important role. They have conducted many good-will missions and have given support to the International Geophysical Year.

Airlift Support of the DEW Line

The urgency of building the DEW Line was so great that in 1955 TAC units were ordered to deliver tractors, equipment, prefabricated buildings, men, and other materiel to remote DEW Line sites. Ships had gone in between the Arctic Islands north of Canada from time to time, but many had been frozen in the ice and destroyed. More important, through the use of airlift, construction work on the DEW Line could begin at least 6 months earlier than it could if ships were used. There also are many DEW Line sites which ships will never reach, including sites on tops of high interior mountains.

TAC–C–124's began operating in Alaska immediately, airlifting tractors, road scrapers, bulldozers, steam shovels, and other heavy equipment from Eielson Air Force Base in Alaska to Arctic strips at Point Barrow, Umiat, and Barter Island. Radar sets had to be airlifted into these sites to permit round-the-clock landings. Moreover, sections of prefabricated buildings were airlifted in, assembled at Point Barrow and Barter Island, and the buildings were moved by sled train along the frozen Arctic Ocean to their destinations.

Shortly after the Alaskan airlift began, the TAC C–124s moved to airfields adjacent to three railheads in Canada, a squadron strong at each site. The squadrons moved into the Canadian airstrips complete with refueling trucks, forklifts, maintenance equipment, and all of the tools and maintenance equipment needed to keep the Globemasters flying. At times they operated from RCAF bases with relatively good facilities, but at other times they operated from remote airstrips.

All of the DEW Line sites, located by aerial reconnaissance, were near some frozen lake or bay on which landings were to be made. (Fig. 116.) In the eastern

FIGURE 116. Tactical Air Command C–124 transports are used in airlift support of DEW line.

Arctic, mainly in the Baffinland and Hudson Bay sectors, many times the ice was made rough by the effects of tidal rise and fall. Since a huge C–124 Globemaster could not land, 17 small tractors were airdropped by parachute from C–119 Flying Boxcars. The airdropped tractors, rigged and loaded at the Air Force base at Frobisher Bay, Baffinland, were quickly put in use to rough out airstrips on which the C–124's could land. Construction workers, food, fuel oil, and small loads of cargo were moved in by civilian aircraft, operating on a contract basis. But all of the large, bulky items were hauled by TAC.

Today, most of the airlift support of the DEW line is carried out by civilian contract airplanes, but TAC continues to move in the large items, mainly by C–130's. In fact, TAC increased its support of the DEW line during the period from April to October 1959, when it began to use C–130's equipped with skis for the job. Moreover, the places that are hard to get to are still a continuing project for TAC H–21 helicopters.

Support of Diplomacy in the Cold War

In considering the peacetime achievements and the expected wartime missions of tactical aerospace power, it is possible to lose sight of a most important immediate mission. In the diplomatic maneuvering of the cold war, the military forces play a very significant and vital role. The presence of powerful U.S. forces overseas give tangible evidence that the United States is ready—and able—to defend its rights and fulfill its obligations anywhere in the world. In its global mission, TAC offers a hand of friendship to its neighbors both here and abroad. Maybe it is a TAC composite air strike force on a training mission to Turkey or a flight to France. Whatever the mission or wherever the location, TAC officers and airmen offer their friendship to the peoples of the free world. In return, our neighbors lay out the welcome mat.

The mutual understanding between TAC and its neighbors is not limited to an understanding of mission and aircraft. For example, doctors of a CASF on TDY to Turkey saved a small boy's life by obtaining plasma for a rare blood disease. In Alaska a TAC troop carrier outfit airlifted sick Eskimos and Indians. At Sewart Air Force Base, Tenn., a unit on a tactical mission included gift packages to Turkish children who in turn sent gifts from Turkey. Other examples of TAC's good-will missions are the airlifting of medicines and equipment to Pakistan following a heavy flood and the airlift of clothing, toys, and books to an orphanage in Athens, Greece.

Also, in February 1960 a special TAC Friendship Force of 30 aircraft and approximately 300 officers and airmen toured the Central Treaty Organization (CENTRO) regional countries of Iran, Pakistan, and Turkey under "Operation Quick Span." This good-will demonstration team spent 21 days conducting aerial demonstrations and static ground displays under the sponsorship of the CENTRO Permanent Military Deputies Group, in coordination with the U.S. Joint Chiefs of Staff.

The first demonstration was given at Teheran before a crowd of 50,000 Iranians, including the Shah and Queen. Another 50,000 spectators applauded

them at Karachi, India, and in neighboring Pakistan, Air Marshal M. Asghar Khan, Commander in Chief of the Pakistani Air Force, was presented with a "Mach Buster's" certificate by TAC's Major General Viccellio after an orientation flight in an F–100F. Similar performances at a number of Turkish Air Force Bases followed before the team returned to the United States.

Another means by which TAC helped to promote good will and to increase U.S. prestige in the cold war was to give support to the International Geophysical Year. Most of TAC's airlift operations for the IGY took place in the Antarctic. But TAC was also responsible for airlifting most of the buildings and heavy equipment for two equally spectacular IGY stations near the North Pole, both on floating ice islands. TAC also airdropped most of the supplies and equipment for a third and almost equally inaccessible IGY station on Blue Glacier, high in the mountains of the Olympic Peninsula in the State of Washington. These Arctic IGY airdrop and airlift operations were made possible through the use of C–124 Globemasters.

ORGANIZATION AND OPERATIONAL CONCEPTS

In preparing tactical air forces to act as deterrents to a general or limited war or to be ready to fight in any kind of war, TAC assumes leadership, as pointed out before. It is the organization that equips the CASF's and trains the men to use the equipment so that these highly mobile units are ready for deployment anywhere in the world at a moment's notice. When a CASF is deployed to the theater, it comes under the jurisdiction of a unified or specified command, which operates under the direction of the Joint Chiefs of Staff. Under present circumstances CASF's are most likely to be deployed to the U.S. European Command or the Pacific Command, in which event they would come under the Air Force component commands USAFE and PACAF, respectively. Today both these commands have tactical units under them. Therefore, these theater commands, as well as TAC, are described here.

Tactical Air Command

The entire organization of TAC is built around developing the CASF, which has become the key to successful tactical air operations worldwide. The three numbered air forces are organized to train and equip these forces. In addition, TAC runs the Air-Ground Operations School to prepare men from the Army and the Air Force to fight in close cooperation.

THE COMPOSITE AIR STRIKE FORCE (CASF).—The CASF was developed as an outgrowth of the Korean War, during which the Soviet Union showed a shift in strategy. By encouraging satellite nations to attack small independent nations and bring them under Communist control, the Soviet Union could continue to enlarge its sphere of influence without risking a global war. The hard fact facing the United States was simply this: if the U.S.S.R. did not choose to fight an open war but continued to harass with a series of small wars, thus bleeding the United States white over a period of time (without undue risk to

itself), then the United States would have to arrive at some solution that would enable it to deter these small wars. The experience in Korea was repeated in Indochina. It has become obvious that the Communists will continue their expansionist efforts through political, economic, and psychological pressures, but they will reserve the threat of force to finally blackmail these small friendly nations.

The demand for a deterrent to limited war led to the creation within TAC of composite air strike forces, each designed to operate with a minimum of support at any distance from the United States. Since the close of the Korean War, TAC has developed and tested the rapid deployment of composite air strike forces and has found the device extremely efficient as a means of deterring limited war.

It appeared to TAC planners that Communist success was due to the lack of sufficient U.S. forces in the immediate area and the speed with which the Communists moved. By the time surface forces were available to repel invasion, key areas of the nation had already fallen to the aggressor. The answer was to be found in highly mobile, well armed units, capable of rapid deployment. Such organizations would of necessity be limited to essentials

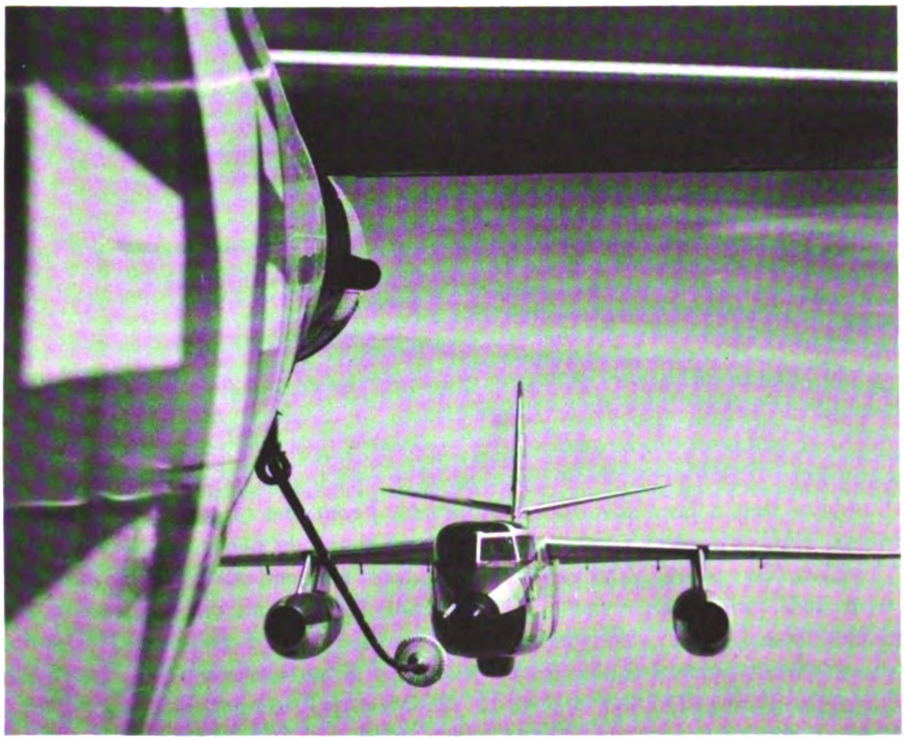


FIGURE 117. An RB–66 reconnaisance bomber moves into position for aerial refueling.

needed for combat and supplies to carry out operations until such time as surface logistic support would become available. The forces would be variable in size to meet any threat with the right amount of force. The force would of necessity be capable of operating as part of existing forces in the area or as a separate entity. Most important of all, the TAC planners set up a criterion that, to be economical, forces should not be specially organized or trained for this specific function. They must have a general as well as a limited war capability.

From this point, the limited war force was rapidly developed. Aerial tankers were acquired (Fig. 117). The "flying boom" system of SAC was tried, but proved to be too slow for the large numbers of fighters. A new system, the "probe-drogue," allowing three TAC jets to refuel simultaneously, was tested and accepted.

Not long after the end of the Korean War, TAC tested the idea of a composite air strike force. A fighter-bomber wing was alerted in California and flew with all of its combat equipment to a base in the southern States. For 30 days the wing operated from a base which had no buildings, no hangers, nothing but a strip of concrete abandoned after World War II. In short, the wing operated with fly-away kits, as it would on any foreign base which lacked the American standard of surface facilities.

Following that first experiment, every unit in the command began refining similar plans and testing them. TAC drew up a standard system and then integrated different types of units into the tests. As part of the planning to implement the composite air strike force idea, in July 1955 TAC activated the 19th Air Force—an air force with no aircraft and no bases—which was to plan for, and be capable of, deploying a CASF anywhere on the globe on short notice. Each force was to be as self-sufficient as possible.

In making up a composite air strike force, TAC uses more than a single type of aircraft. Actually each strike force represents a miniature Air Force itself. It contains tactical fighters to obtain air superiority, tactical fighters for close support, interdiction, and counterair operations, and light tactical bombers for an all-weather capability and longer range tactical missions. Also included are tankers and cargo aircraft for support functions en route and support operations after arrival. Once a CASF arrives, it is ready for operation. It has the minimum essential manpower, spare parts, and equipment, right down to mess kits.

Suppose that nation X has military forces massing on its border and indications are that a land invasion is imminent. From one of several contingency plans, TAC can select a force of the size and character needed to deal with the situation. The entire initial combat and support element can then be committed with little more than a few telephone calls. Routes and refueling points are selected from plans tested through previous deployment exercises. The entire movement may be timed to arrive at nation X so that operations can begin immediately, if necessary.

Now the primary purpose of this force is not to fight, although it can if necessary. It is a deterrent force. If it can arrive quickly, there probably will be no aggressive move on the part of the opposing nation. A would-be aggressor

is unlikely to undertake a military campaign without favorable conditions for success.

TAC's strike forces are equipped and trained to deliver nuclear bombs. They can take tactical atomic weapons into virtually any area and deliver them successfully against well defended positions. TAC's tactical fighters and tactical bombers can deliver a bomb to a target, evading enemy automatic weapons fire and radar by flying and bombing at low altitudes, with the low-altitude bombing system (LABS). This can be done at the risk of one aircraft, which can deliver the firepower which a decade ago took thousands of bombers. Tactical aircraft thus represent an economy of force previously unknown in military history. A handful of men and aircraft, acting under a centralized control, can move very quickly and strike with tremendous effect.

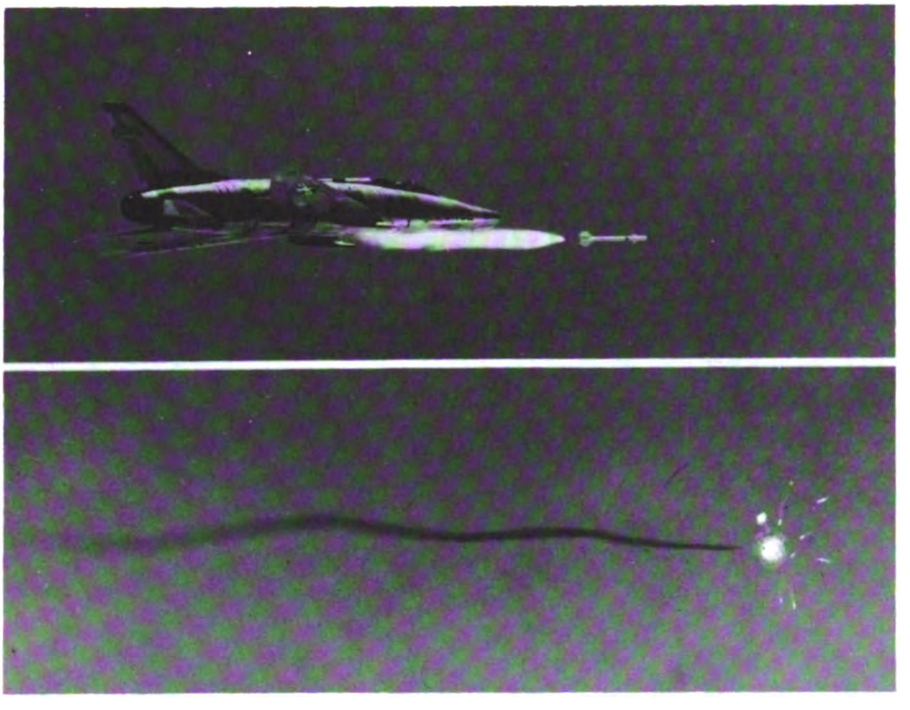


FIGURE 118. An F–100 Super Sabre fires the GAR–8 Sidewinder.

In regard to these small wars and the missions TAC aircraft will perform, there should be a refutation of a popular misconception concerning the nuclear bomb. Tactical forces will be attacking military targets in the field, not population centers. They will hit at the aggressor's military supply lines, not his industrial complex. It will not be TAC's purpose to beat the aggressor to his knees through mass retaliation, but to halt his aggression through selective destruction

of military targets. These things TAC can do quickly and decisively without great loss of life.

Within the structure of the U.S. Air Force and TAC are communications facilities that cut reaction time to a minimum. TAC combat crews are never more than a telephone call from their aircraft, and TAC forces are ready for any emergency. Every man knows his job—but more important he knows, understands, and believes in what he is asked to do.

The first experiment in rapid movement of a complete CASF overseas came in 1956. Called Mobile Baker, a strike force was launched from the United States into North Africa. Fighters made the nonstop trip in less than 5 hours from a Newfoundland base to North Africa. As fighters, bombers, and reconnaissance aircraft landed on the North African base, they received orders moving them into other bases in Europe. The strike force proved it was possible to move vast amounts of men and materials rapidly across the Atlantic. Further experiments were carried out in 1957.

After 4 years of concentrated effort to develop such a CASF, the first opportunity to prove its value came on July 15, 1958. The morning Marine troops

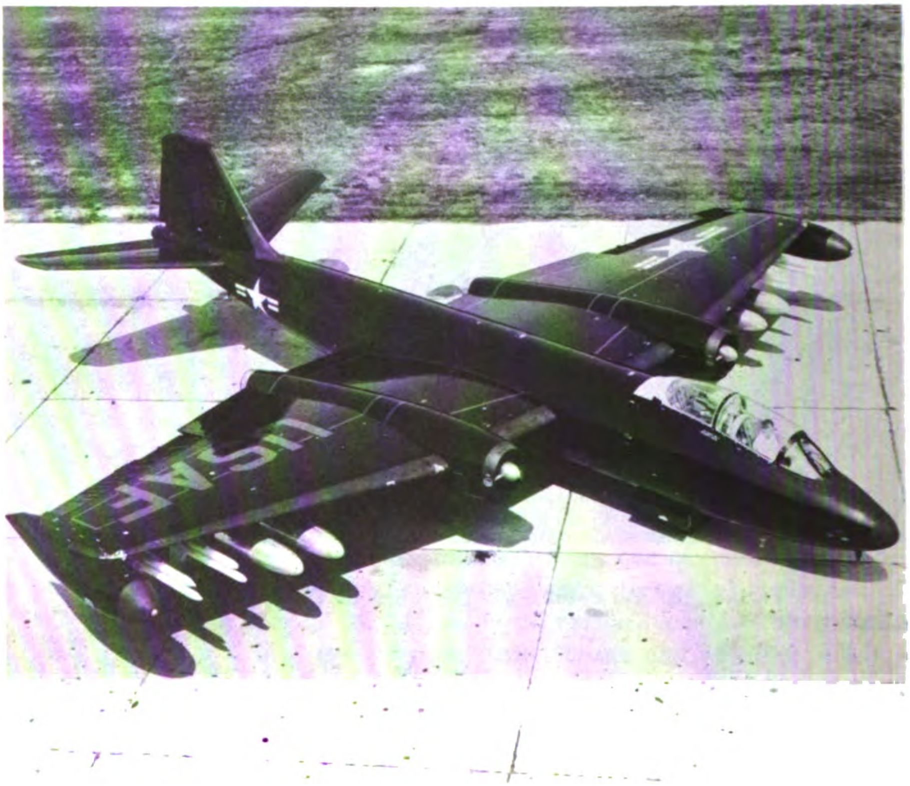


FIGURE 119. The B–57 Night Intruder, carrying rockets and napalm bombs on wing pylons.

went ashore in Lebanon after a Presidential directive ordered aid to the tiny nation, a CASF was alerted. Three hours later B–57 tactical bombers (Fig. 119) were en route to the Middle East. In another 3 hours TAC aerial tankers at mid-Atlantic bases were alerted to the fact that F–100 tactical fighters had departed Myrtle Beach Air Force Base, S.C. Also airborne were RF–101 and RB–66 reconnaissance jets from Shaw Air Force Base, S.C. Twelve hours later the first of the F–100 fighters popped their drag chutes at Adana Air Base, Turkey. The shift of military power in the Middle East had begun.

Within 48 hours Adana changed from a virtually unused Turkish gunnery base to a thriving hub of American airpower. In place were all the elements of a modern tactical air force. A fully manned air operation center, staffed by the 19th Air Force CASF command, was in operation and was integrated with Navy, Marine, and Army forces located in the Mediterranean area.

TAC had occasion to test the CASF again a short time later when the Chinese Reds announced their intention to "liberate" Quemoy. A second CASF was organized from plans that had been tested 9 months earlier when B–66 tactical bombers had arrived in the Philippines only 17 hours after launching. Once again a CASF was on alert, this time with its bases in the Philippines, Okinawa, and Formosa, making a ring around the troubled area.

F–100 tactical fighters from the strike force, armed with the Sidewinder missile, appeared over Quemoy. The F–101 Voodoo tactical fighters, with their smashing firepower remained out of sight, but their presence was known to the Communists.

While these operations proceeded in the Far East, a team of TAC pilots arrived from George Air Force Base, Calif., and began training Chinese pilots on Formosa to fly the F–100. The command's 507th Communications and Control Group moved into the Formosan woods and set up a modern radar facility for the CASF. The force was integrated with Pacific Air Forces, the CASF commander being assigned a key post as chief of the Joint Operations Center in Formosa.

The CASF proved its value. Such a force, properly trained and equipped, could operate successfully either independently or in conjunction with theater forces. Despite its success as a deterrent in exercises and employment, TAC is not resting on its laurels. Innovations are constantly being studied for the force, force structures are changed in accordance with world situations, and new men and units are selected for the CASF.

TAC has multiplied its air power potential through the combined resources of industry and research organizations which have given it in-flight refueling, higher performance aircraft (Fig. 120), and tactical nuclear weapons. As a result, TAC is today filling a vastly broadened role as a major deterrent to small wars, while still maintaining powerful tactical air forces in readiness for employment against any aggression.

The Three Numbered Air Forces.—The Tactical Air Command, from its headquarters at Langley Air Force Base, Va., supervises its many subordinate units through its three numbered air forces: the 9th Air Force, with head-

FIGURE 120. A single aircraft like the F–105 can deliver tremendous firepower.

quarters at Shaw Air Force Base, S.C.; the 12th, with headquarters at Waco, Tex.; and the 19th, at Seymour Johnson Air Force Base, N.C. The 19th Air Force provides a highly mobile command element capable of assuming operational control of attached forces to participate in tactical air operations in any area of the world. It has a headquarters and whatever else the operation demands. The 19th Air Force exercises control of the CASF.

The missions of the other two numbered air forces of TAC are generally similar: each is directed to command, organize, equip, train, and administer assigned or attached forces to participate in tactical air operations. More specifically, both the 9th and 12th Air Forces are directed to provide trained forces for the augmentation of overseas unified commands, for participation in CASF operations, for air defense of the United States, and for such exercises, movements or demonstrations as may be assigned. In addition, the two air forces must provide trained cadres around which units can be organized, train and inspect Air Force Reserve and Air National Guard units, and assist in disaster relief as necessary.

In addition to the above listed common missions, each of the two "peacetime" TAC air forces have specified missions. The 9th Air Force is charged with pro-

viding flight delivery service of aircraft where needed, the operation of the USAF Tactical Missile School, and the operation of the USAF Advanced Flying School (Tactical Reconnaissance). The 12th Air Force operates the USAF Fighter Weapons School, supervises the Combat Crew Training Wings, tow target and aerial tracking operations, and conducts special flying training programs for the Air National Guard and selected foreign flying students. In support of their missions, both numbered air forces are authorized individual headquarters, tactical units, and support units. The 9th Air Force is authorized additional missile, aerial tanker, troop carrier, reconnaissance, and communication and control units.

USAF Air-Ground Operations School.—Unique in TAC's organizational structure is its USAF Air-Ground Operations School (AGOS). This school was established at Fort Bragg in September 1950 and moved later to Southern Pines. In February 1957 the school moved to Keesler Air Force Base, Miss.

Inter-service cooperation and teamwork are the keynotes of the AGOS, which provides continuing instruction in air-ground operations. Heading the staff of the school is an Air Force officer who serves as commandant. Deputy commanders are one Air Force and one Army officer. USAF, Army, and Marine Corps officers serve on the faculty. Resident students are officers and some key civilians of all the services. The school also reaches nonresident students through the traveling Joint Air-Ground Instruction Team which visits Air Force and Army installations and gives instruction in methods and procedures by which air forces and surface forces in theaters of operations plan, integrate, and conduct joint efforts in area operations.

AGOS offers several courses. The students first attend the Indoctrination Course, which familiarizes them with the doctrine, methods, techniques, and procedures by which air and surface forces in an area of operations accomplish joint planning and coordinate their efforts to fulfill the common mission. The Specialist Course prepares students primarily from Tactical Air Command and the U.S. Continental Army Command, to perform special duties in the Air Force Tactical Control and Operations System (TACOS) and Army Air Ground System (AAGS). Air Force students are prepared for Air Liaison, Intelligence, Reconnaissance, or Operations Officer slots. Army students train to fill such positions as Ground Liaison Officer, G–2 (Intelligence), G–3 (Operations), or S–3 Air Officer. The Specialist Army course's objective is to train ground force personnel who are either occupying or under training to occupy positions concerned with air-ground operations at every echelon. The Forward Air Controller's Course trains a reservoir of Air Force pilots to direct visually air strikes against surface targets from forward ground observer positions.

The constant changes in the tactics, techniques, and procedures of air-ground coordination are reflected in the instruction given at the school. For example, much of what was learned about coordinated and combined air-ground operations during the Korean War has been integrated into the AGOS curriculum. Moreover, TAC and the Continental Army Command continually review and improve the latest techniques for adaption to the newer weapons and concepts.

USAFE AND PACAF.—In addition to the tactical forces stationed in the United States as a part of TAC, there are tactical units stationed abroad as integral parts of U.S. Air Forces in Europe (USAFE) and Pacific Air Forces (PACAF). These two major air commands are theater air commands, with numbered tactical air forces.

USAFE maintains a combat force in Europe and the Middle East in support of NATO and the free countries in this area of the world. Subordinate headquarters are maintained in England (3d Air Force), Germany (17th Air Force), France (332d Air Division), Spain (65th Air Division), Saudi Arabia (2d Air Division), and Turkey (the 7217th Air Division, or TUSLOG: The U.S. Logistics Group). USAFE has its command headquarters at Wiesbaden, Germany. The USAFE area of responsibility covers roughly 18 million square miles.

In wartime, most USAFE units would become a part of the North Atlantic Treaty Organization (NATO) and would receive their direction from Supreme Headquarters Allied Powers Europe (SHAPE). In peacetime, USAFE itself is a component of the U.S. European Command (EUCOM). When USAF Gen. Lauris Norstad assumed his duties as Supreme Allied Commander Europe (SACEUR), he was also Commander in Chief European Command (CINCEUR). Thus, in one individual, command of both SHAPE and EUCOM were merged.

USAFE in the past has been called upon to counteract Communist moves in Europe and the Middle East. One of the first of these was the dramatic Berlin Airlift. During the Suez crisis USAFE units transported hundreds of troops from Scandinavia to Italy, and over 8,000 tons of supplies from Europe to the Middle East during the Lebanon crisis. At the time of the latter incident a detachment of the 86th Fighter Interceptor Wing was sent to Adana, Turkey, to provide all-weather cover for TAC's CASF deployment to that point. In the 1960 Congo unrest, USAFE transported United Nations men and materiel into Congo and evacuated civilians.

On the other side of the world is a comparable major air command, Pacific Air Forces (PACAF), which represents the air component of the unified Pacific Command. Headquarters PACAF is at Hickam Air Force Base, Oahu, Hawaii. Its subordinate headquarters are the 5th Air Force, with forces in Japan, Okinawa, and Korea; the 13th Air Force, with units in Philippines, Taiwan, and Guam; the 315th Air Division in Japan; and the Hawaiian Air Defense Division in Hawaii.

PACAF has organized a small mobile strike force of its own, Air Task Force 13, with a capability of rapid deployment and critical area buildup, similar to TAC's CASF. The Quemoy crisis clearly demonstrated the nature of Communist intentions to drive the United States from the Pacific, but PACAF's mobility provides the greatest stumbling block to those intentions.

In addition to its other missions, PACAF also provides training and support to the air forces of eight Far East countries: Cambodia, Laos, Vietnam, Thailand, Philippines, Japan, Korea, and Taiwan. The total aircraft of these nations

outnumber those of PACAF, but they are not so modern. Through intensive training by PACAF instructors, the air force personnel of these countries can cope with the disadvantages which might otherwise occur in conflict with the enemy's faster aircraft.

In both the Pacific area and the Middle East, Air Force tactical units have proved their value. Tactical air forces, together with strategic and air defense forces, comprise the combat elements of the U.S. Air Force.

CHAPTER 13

ASTRONAUTICS

It is important to consider how progress in astronautics relates to research and development of aerospace weapon systems. According to the official Air Force definition, astronautics is "the art or science of designing, building, or operating space vehicles." Much of what appears in this chapter has, therefore, a military implication.

The basis of aeronautical knowledge lies in an understanding of the medium of space where the vehicles are to operate. Gaining and utilizing this knowledge

◀ Approximately 200 miles up the main stage of the Atlas can be seen falling away after separation from the nose cone.

is largely within the province of engineers, physicists, and astronomers. Any vehicle or payload that penetrates the atmosphere and travels through space represents a major engineering feat, and the vehicle and its payload, once in space and not under power, travel along paths governed by the same laws as those that control the orbits of the planets, the comets, and other heavenly bodies. But engineering, physics, and astronomy do not nearly supply all the information that the space scientist requires. He also draws upon contributions made from meteorology, geophysics, astrophysics, cosmic-ray physics, aerodynamics, radiobiology, physiology, aviation medicine, space medicine, human engineering, and other fields of knowledge.

While it is true that astronautics is distinct from aeronautics, and that a space vehicle encounters problems differing from those of an aircraft and must use different methods of control, it is also true that a space vehicle must first fight its way through the envelope of air surrounding the earth, and it must return through the atmosphere. In attempting to solve the exit and reentry problems, astronautical scientists find they can secure valuable information from aeronautics, and the division between the two sciences may not be so distinct in the future.

At the present stage in the development of astronautics, the United States is first of all concerned with basic knowledge. As the fund of basic knowledge about space and space travel grows and as technology advances, the Nation and the Air Force will be able to extend its capabilities into outer space.

The avowed national intent is to use space knowledge for peaceful purposes, and to this end the Air Force is cooperating actively with the National Aeronautics and Space Administration in supplying boosters for its experiments. Until such time as this agency can put into use the family of superboosters that it is developing, the Air Force will continue to supply boosters. Also, by a specific directive of the President, the Air Force furnishes boosters for all military space experiments: for those of its own service, as well as for the communications experiments of the Army and the navigation experiments of the Navy.

Pioneering in space will almost inevitably open great new areas for military exploitation, as well as peaceful pursuits. The Congress of the United States, realizing that the Nation cannot afford to neglect its defenses by ignoring this fact, has recognized by law the place astronautics must have in future aerospace weapon systems. Section 102b of the National Aeronautics and Space Act of 1958 provides ". . . that the general welfare and security of the United States requires that adequate provision be made for aeronautical and space activities." Further, even though a civilian agency shall exercise control over much of the primary research, ". . . activities peculiar to or primarily associated with the development of weapon systems, military operations or defense—including research and development—shall be the responsibility of the Department of Defense."

As a means for understanding how artificial satellites orbit and how space vehicles travel, it is necessary to consider first the nature of space itself; the background knowledge that made space exploration possible; and the order

of the natural satellites, the planets, and the sun as part of the universe. The first question that the student of astronautical science must ask himself is: What is the fundamental nature of space?

WHAT IS SPACE?

At about 1,000 miles above the earth, the exosphere, or the last layer of the atmosphere, is considered to end, and beyond this space begins. The denser portion of the atmosphere of the earth, however, extends only about as far above the surface as the oceans extend below the surface, which is about 3 miles. From this point on, the air gradually becomes thinner until at 800 to 1,000 miles above the earth it is almost incredibly rarefied. A vehicle at an altitude of 1,000 miles would have penetrated the last remnants of the atmosphere and would be in cislunar space, the region between the outer atmosphere and the moon's orbit.

The conditions of space are difficult for the earth-dweller to imagine, since they represent an absence of most familiar things, and the few ordinary objects that would remain, such as his view of the sun and the stars, would take on a vastly altered appearance. Men who have flown to high altitudes in balloons or who have surged upward from powered flight in jets have described how the vault of the heavens changes from a deep blue to inky blackness even within the reaches of the atmosphere. In space, far out from the blanketing effects of the atmosphere, there is an absence of diffused light, thermal convection, sound, oxygen, barometric pressure, the support and stabilizing influence of the ambient air, and the filtering buffering effects of gases which protect man from cosmic rays and other harmful radiations. Here also there is no adjustment comparable to that effected by the cycle of day and night. Also, as a vehicle travels out from the earth, the gravitational pull gradually but slowly decreases until at about 1,000 miles out it is only about 65 percent of what it was at sea level.

In terms of the vastness of space, the amount of matter that is present can, for most practical purposes, be ignored. There are occasional meteoroids and charged atomic particles moving at a considerable speed. But, as Arthur C. Clarke, formerly chairman of the British Interplanetary Society, has calculated, a volume of space equal to that occupied by the entire planet Earth would contain only about a quarter of an ounce of meteoroids and 2 or 3 ounces of hydrogen! No vacuum has ever been produced on the earth that is comparable to that prevailing in space.

Likewise, the jet-black darkness of space can rarely be duplicated on earth. On earth absolute darkness does not occur in places shielded from the sun or other light sources because there is always some diffused light present in the shadow as a result of refractions and reflections within the atmosphere. The stars, which in space no longer appear to twinkle because the viewer is no longer in an atmosphere of varying density which diffracts the starlight unevenly, show at all times against the inky blackness, even adjacent to the sun, which is a brilliant, blinding orb.

Because there is no diffusion of sunlight in space, there is no heating or cooling in the same sense as within the atmosphere. When a scientist speaks of the temperature of space, he assigns the absolute-zero figure of $-273°$ C. This merely refers to the absence of molecular or atomic motion. Because space is an almost perfect vacuum, no perceptible heat in this form can be present outside of solid bodies.

Solid bodies in space acheive what is known as equilibrium temperature. Suppose such a body in space is located near the earth. One side of the body is in the complete shadow of the sun and the other is in full sunlight. The side that is in the sunlight will become extremely hot, especially if it is dark in color so that it readily absorbs radiant heat energy. A black body outside the earth's atmosphere and exposed to the sun's rays at earth's distance from the sun might become so hot, for example, as to reach the temperature of boiling water on earth. If the body were white or silvered instead of black, so that it reflected most of the heat, it might be quite cool. Because heat can be transmitted from one body to another in airless space only by radiation, a body subjected to the action of solar rays is heated or cooled until the quantity of heat absorbed by it becomes equal to the amount of heat radiated. Then the temperature becomes established at a constant level known as the equilibrium temperature. In addition to color or degree of darkness, the equilibrium temperature of a body in space depends upon the material from which it is made, the shape of the body, the portion of the surface exposed to the rays of the sun, and the distance of the body from the source of radiant heat.

The equilibrium temperature principle is used in designing space vehicles. For example, if a structure is intended to attract heat from the sun, it is painted black, and as much of its surface as possible is exposed to the sun. It is easy to see that temperature variations found in solid bodies in space are vastly greater than those occurring on the earth.

Just as there is an absence of heat (molecular or atomic motion) in the vacuum of space, so there is an absence of sound. As soon as the molecules of gas in the earth's atmosphere are farther apart than the length of the sound waves, the silence of space begins.

Because in space there is an absence of oxygen for breathing, as well as danger from harmful radiation, man must travel in a sealed and shielded cabin providing an acceptable environment. This will be described later.

Space vehicles, while "coasting," are in a condition of apparent weightlessness. Unless some capability were incorporated in a space vehicle to provide artificial "weight" to passengers, perhaps by such action as rotating the vehicle to provide centrifugal force, the condition would exist throughout the entire voyage through space except for the relatively brief periods when the vehicle was subjected to powered thrust.

So far the question as to what space is has been answered in terms of conditions existing far beyond the reaches of the atmosphere. This approach has been used in an attempt to arrive at the simplest possible explanation: space is the absence of the atmosphere surrounding the earth and all that it represents.

Despite what was said earlier about the boundary where space begins, that definition was too simple. Astronautical engineers must vary their answers to fit varying situations; space begins at different altitudes for different purposes. At relatively low altitudes the progressively changing characteristics of the atmosphere cease to support one function after the other, and the altitude at which a function stops is known as the space-equivalent altitude for that function.

For man, space is quite near. At an altitude of 3 miles he requires supplemental oxygen or some acclimatizing to become accustomed to the thin atmosphere. At 5 miles he must use supplemental oxygen, but he can expose himself for brief periods to the rarefied atmosphere without fatal results. At 8 miles man encounters space-equivalent conditions with respect to lack of oxygen and must depend on pressure-breathing. At 12 miles the body fluids begin to boil for lack of atmospheric pressure. At about 15 miles the density of air is so low that a sealed cabin carrying its own gas supply for pressurization is necessary.

For an aircraft, which depends upon aerodynamic support from the atmosphere, space begins at about 30 miles, or roughly three times farther up than it does for man. This altitude of 30 miles represents the limit for useful aerodynamic lift and for attitude control by means of conventional control surfaces. Above this altitude the flight engineer deals with ballistics, and navigation by conventional control surfaces has to be replaced by reaction control.

The rocket engineer asks where space begins for him. By this he means the point at which air resistance become, for practical purposes, zero. Above this point the rocket engine is in what is, for most purposes, a vacuum, and it per-

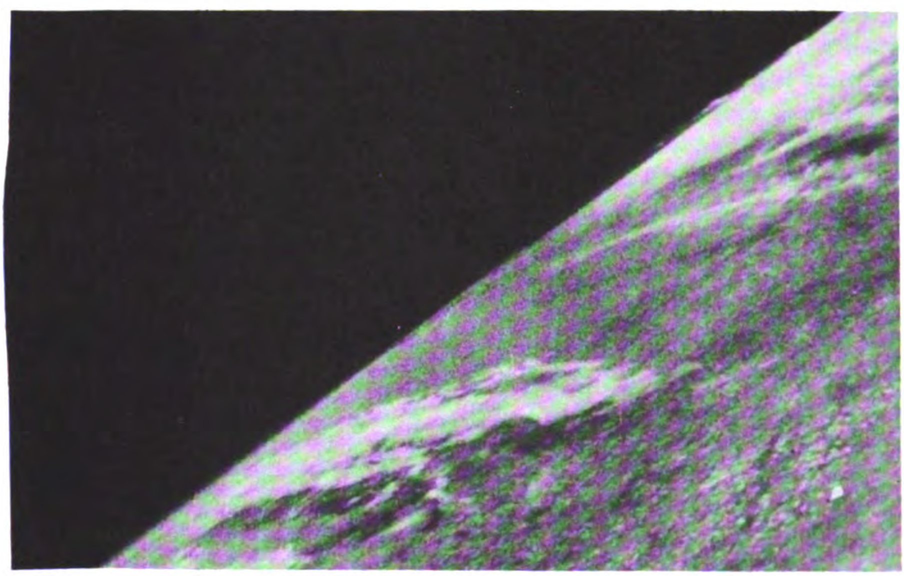


FIGURE 121. The horizon as photographed at an altitude of 65 miles. The picture shows 40,000 square miles of the earth's surface.

forms at almost peak efficiency because there is almost no air resistance to slow it down. The physical border between air and space depends a great deal upon the point where atmosphere becomes insufficient to support this or that purpose. Above 160 miles most rockets are considered to be in space, because atmospheric molecules are so rare that their resistance is almost insignificant.

One might go on determining what represents space according to the different functions served by the atmosphere. The strange darkness of space is reached at 60 to 80 miles, the transition zone from atmospheric to space optics. The silence of space begins in the same 60-to-80-mile zone. It is in this region also that mach numbers become meaningless when referring to speed.

As one goes on considering space in terms of the lack of atmosphere, there is a danger that he might think of atmosphere as the general rule and space as the exception. It is, in fact, quite the other way around when one considers the planetary system of which the earth is a part. The earth is the only known planet in our solar system that has a layer of atmosphere with an abundance of free oxygen and water vapor.

While the atmosphere supports life on earth, it is also something of a barrier to space travel. Outside the atmosphere, space vehicles have no ceiling, no weather, and almost no molecular resistance. Initial velocities relative to sun, planet, or moon, are altered only as gravitational forces from this or that celestial body act upon them.

SPACE PIONEERING BEFORE SPUTNIK I

Space travel might be said to have begun in October 1957, when the U.S.S.R. launched the first artificial satellite, the famous Sputnik. This date is usually agreed upon, although some scientists say that space exploration really began when a Wac Corporal rocket ascended to the record height of 250 miles in February 1949 and then fell back to the earth.

Whatever date is agreed upon, the fact remains that space probing by man-sent vehicles was not begun until modern times. Man had spent centuries in exploring the planet Earth. He had set out on voyages on unknown seas and had extended his knowledge of the earth to the highest mountains and to the arctic and antarctic wastes, but he had reserved space exploration until last. Before man was ready to attempt space travel, he first had to crystallize his knowledge about the planetary system and about the way a body acted in space. Then he had to work out the mathematics of the orbits and trajectories. Two experimental physicists and astronomers of the 16th century, Galileo and Kepler, and Newton of the next century, stand out as pioneers who discovered basic laws of nature which eventually had application in pioneer space exploration.

There was early realization that a reaction motor like that of the rocket would permit man to operate independently of the atmosphere. Development of such a rocket motor to a point where it could impart enough velocity to a vehicle to counterbalance the gravitational pull of the earth had to await the technology of the mid-twentieth century.

Man was able in recent times to progress to the frontiers of space travel because of the bold imagination of many generations of philosophers and literary men and the painstaking work of mathematicians and astronomers. The final impetus to launching the artificial satellite came from governmental and scientific organizations, following development in Nazi Germany during World War II of rockets of sufficient size and power to penetrate the atmosphere.

A multitude of scientists, mathematicians, engineers, laboratory workers, and Government officials have made substantial contributions to space research. It is not the intent here to attempt to summarize all their work but rather to outline some of the beginnings made by pioneers.

Three men are especially credited with pioneering rocket flight and space exploration in recent times: Robert H. Goddard, of the United States; Herman Oberth, a German born in Transylvania; and Konstantin Tsiolkovsky, of the U.S.S.R. Robert Esnault-Pelterie, of France, a pioneer aviator, is credited perhaps erroneously, with first using the term "astronautics." He helped to encourage progress in astronautics by influencing a Parisian banker to set up a prize, he gave lectures on the subject, and published a paper about astronautics in 1928, but his contributions were not comparable to those of the first three men named.

Dr. Goddard (1882–1945), known as the Father of Rocketry, did not, of course, develop the first rocket. There are records that rockets were used by the Chinese as early as the 13th century in repelling the attacks of the Mongols. But Goddard, in March 1926, launched the world's first liquid-fuel rocket. The distance covered was only 184 feet, but the flight proved that this type of rocket could be developed.

Some 6 years before, the Smithsonian Institution had published Goddard's report entitled "A Method of Reaching Extreme Altitudes." This remarkable work presented detailed calculations on the use of rockets. It discussed the step rocket, rocket clusters to gain additional thrust and performance, and parachute recovery of instruments fired to great heights. The report pointed out that a rocket might be shot to the moon, and it went on to calculate the amount of flash powder that would be necessary to signal its arrival.

During most of Goddard's lifetime the public was not ready for serious speculations about travel to the moon, and even scientists severely criticized Goddard's theories about sending rockets into airless space in the 1920's. Nevertheless, Goddard went on with his work, constantly experimenting and improving the liquid-fuel rocket. By 1935 one of his rockets reached an altitude of 7,500 feet. Another, controlled by a gyroscope and by vanes in the rocket exhaust, rose to 4,800 feet and then flew horizontally for more than 2½ miles. By the late 1930's Goddard was recognized, at least in professional circles, as among the world's foremost rocket scientists. His works and patents were well known to the members of the German Society for Space Travel.

Three years after Goddard's work appeared in the United States, Herman Oberth (born in 1894) published his book *The Rocket Into Interplanetary*

Space (1923) in Munich. In this book he set about to prove that space travel was possible. He considered the rocket merely as a prototype of the space ships that were to come. To him and to his followers, every step in the development of the rocket was just one more step toward interplanetary travel.

In 1927, Oberth and an enthusiastic group of German youths established the German Society for Space Travel. Later some of its members, among whom was Wernher von Braun, Willy Ley, Klaus Riedel, and Rudolf Nebel, founded the Rocket Proving Ground at Berlin. The early experiments of the German scientists, as well as their later work and the V–2 experiments in the United States, are described in an interesting manner by Willy Ley in his book *Rockets, Missiles, and Space Travel*. He relates how the German Government called upon the young scientists in Berlin and interested most of them in working with General Dornberger at Peenemunde. Here, from 1936 to 1945, the German Government carried on a $100 million program for rocket development. It finally resulted in the A–4 (the later V–2) rocket, which was first launched successfully in 1942. (Fig. 122.) Largely from the work done at Peene-

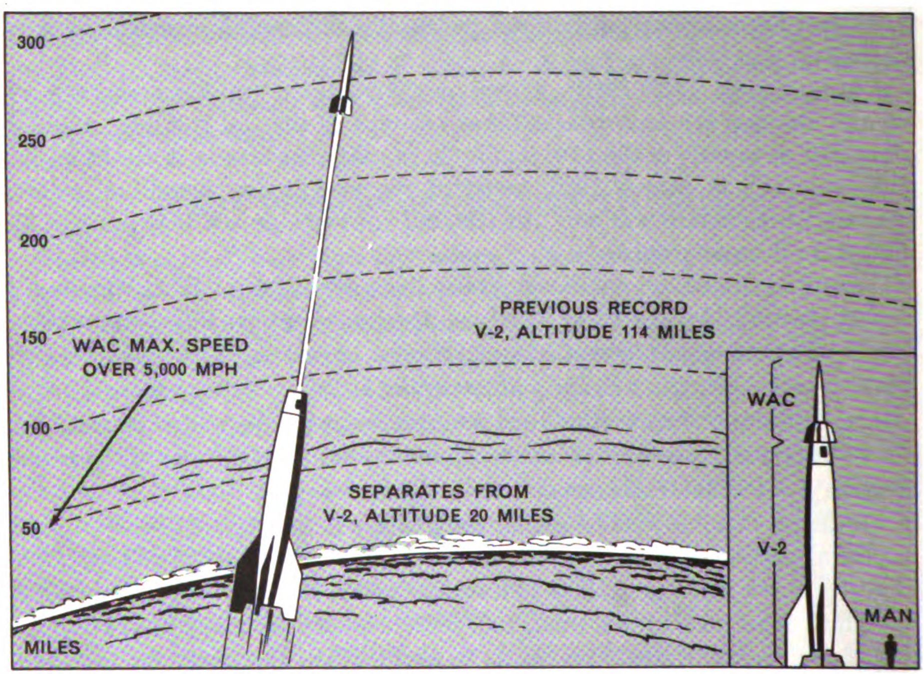


FIGURE 122. Early experiments with two-stage rockets used captured German V–2 missiles.

munde, the ballistic missile programs in both the United States and the Soviet Union had their beginnings. Much further progress had to be made, however, before space travel was possible.

While Herman Oberth was working on his book setting forth the theoretical basis for space travel, he was unaware that a school teacher named Tsiolkovsky had already published information on the subject in the U.S.S.R. Strangely

enough, Tsiolkovsky was in a sense rediscovered in his own country in 1924, a year after Oberth's book appeared in Munich.

Konstantin Tsiolkovsky (1857–1935), known as the Father of Astronautics, established the mathematical formulas for space flight with liquid propellants. He first conceived of the possibilities of space travel in 1873. The story is told that he was so excited at the time that he did not sleep all night but walked about Moscow thinking about the consequences of his great discovery. From that time on Tsiolkovsky, although deaf and desperately poor, worked with remarkable devotion throughout his long life to further the cause of space travel. By 1898 he had put down all the basic ideas for space travel, including a detailed survey of a spaceship propelled with liquid fuels, in a manuscript entitled "The Exploration of Planetary Space with Reactive Equipment" and sent the manuscript to the publisher of the Soviet periodical called the Scientific Review. The editor did not have the courage to print the article until 1903. When it appeared, Tsiolkovsky took new hope, and from then to 1926 published many articles and books. In 1920 he received some recognition from the Soviet Government for a science-fiction story that he had written much earlier, but his scientific work was not fully recognized in his country until near the end of his life. The followers of Tsiolkovsky established the organization known as GIRD (Group for the Study of Reactive Motion).

It is fascinating to conjecture what might have been the effect on the history of astronautics if Goddard, Oberth, and Tsiolkovsky had freely shared their ideas as members of the same learned society. Largely as the result of the work of these men, however, the impetus was given to founding astronautical societies.

Just as the German Society for Space Travel was founded in Germany and GIRD in the Soviet Union, astronautical societies were formed in all the leading countries in time, and these societies participated in international congresses. The American Interplanetary Society, later renamed the American Rocket Society, was formed in New York a few years after the German society. A year or two later the British Interplanetary Society began. At meetings of these societies one of the most important problems discussed was the launching of an artificial satellite, the first step toward space exploration.

Post-World War II Scientific Organizations

On October 4, 1954, the Special Committee for the International Geophysical Year of the International Council of Scientific Unions adopted a resolution that an artificial earth satellite be launched. During the following month the Space Flight Committee of the American Rocket Society submitted a report on the subject to the U.S. National Science Foundation. The National Academy of Sciences, the sponsoring agency for the United States turned to the National Science Foundation for funds. In the spring of 1955, members of both organizations petitioned the President of the United States to have this country sponsor an artificial satellite as part of the program for the International Geophysical Year (1957–58). In July of the same year, the President announced the plan for a U.S. satellite. In August, Professor Sedov, of the Soviet Union,

while attending the Sixth International Astronautical Congress in Copenhagen, stated that the Soviet Union would also launch a satellite in 1957. Man was proposing probes of space that would eventually take him into the realms of the astronomer.

THE SOLAR SYSTEM

To arrive at an understanding of the fundamentals of space travel, one must consider the earth, the planets, and the sun from the viewpoint of the astronomer. Assuming this viewpoint may require some stretching of the imagination. The distances between the parts of the solar system are vast indeed, and the velocities at which the planets travel are enormous, but if space travel is to become a reality, man must learn to cope with these distances and achieve these velocities. Not all factors in space travel are adverse or restrictive. For example, if a body were to travel into space and come under the influence of the gravitational pull of first one planet or satellite and then another, little additional power would be needed to transfer it from orbit to orbit at enormous velocities.

Because of the enormous distances between the parts of our solar system, it is difficult to represent on the same scale the sizes of the planets and the distances between them. Mikhail Vassiliev, the Soviet space scientist, estimates that it would take more than the area of a large stadium to represent the solar system to scale by distances, if the planets and their satellites were to be shown large enough to see easily and to appreciate their relative sizes—in relation to each other and to the sun.

The nine planets of the solar system (Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, Neptune, and Pluto) move in the same direction around the sun in near circular orbits (ellipses of low eccentricity) (Fig. 123). Except for

TABLE VII

THE PLANETS

Planet	Date of Discovery	Planet's Distance from the Sun	Diameter	Period of Orbit	Orbital Velocity	Period of Rotation	Escape Velocity	Closest Approach to Earth
		(Miles)	(Miles)		(Mi/sec)		(Mi/sec)	(Miles)
Mercury	Known and observed since classical times	36,000,000	3,100	88 days	29.7	88 days	2.3	50,000,000
Venus	Known and observed since classical times	67,270,000	7,575	224.7 days	21.7	Unknown	6.3	26,000,000
Earth	Known and observed since classical times	93,003,000	7,900	365 days	18.5	1 day	7.0	—
Mars	Known and observed since classical times	141,710,000	4,268	687 days	15.0	24 hrs 37 min	3.1	35,000,000
Jupiter	Known and observed since classical times	483,900,000	89,329	11 yrs 314 days	8.1	9 hrs 55 min	37.0	367,000,000
Saturn	Known and observed since classical times	887,200,000	75,021	29 yrs 168 days	6.0	10 hrs 14 min	22.0	745,000,000
Uranus	1781	1,784,800,000	32,219	84 yrs	4.2	10 hrs 40 min	13.0	1,691,797,000*
Neptune	1846	2,793,700,000	33,000	164 yrs 26 days	3.4	15 hrs 40 min	14.0	2,700,697,000*
Pluto	1930	3,675,300,000	4,000	248 yrs	2.7	Unknown	6.5	3,582,297,000*

*Approximate figure

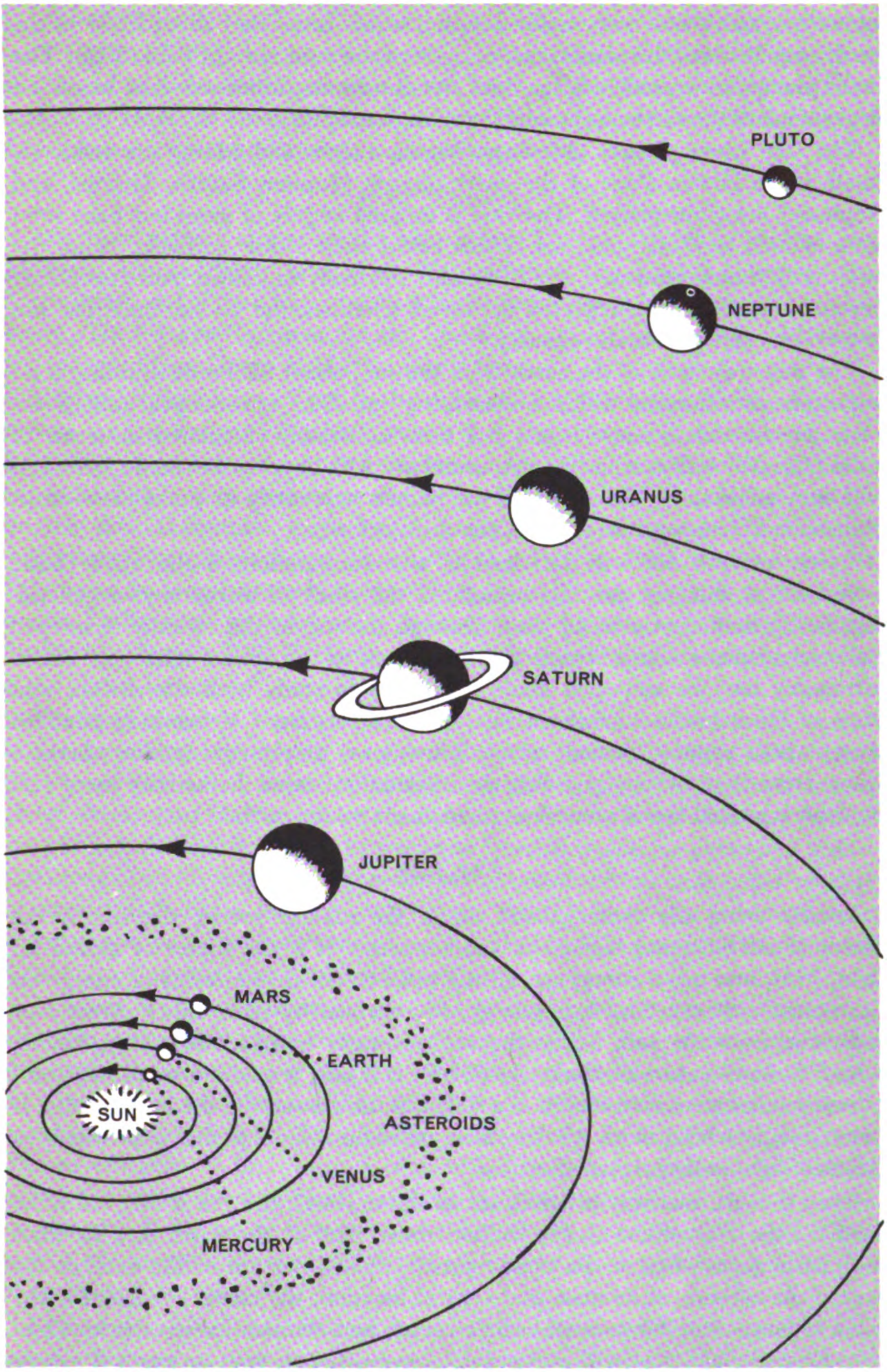


FIGURE 123. The solar system.

the orbit of Pluto, all orbits of the planets are in approximately the same plane, known to earthly observers as the ecliptic, which is inclined about 23.5° to the earth's equator. All the planets do not move at the same speed (Table VII). The inner planets move much faster than the outer ones, otherwise they would be drawn toward the sun by its powerful gravitational pull.

The four inner planets (Mercury, Venus, Earth, and Mars) are relatively small, dense bodies. Four of the outer planets (Jupiter, Saturn, Uranus, and Neptune) are giant planets. They are composed largely of gases but have solid ice and rock cores at unknown depths below their visible surfaces. Pluto, the outermost planet, relatively small, remains relatively unknown. Another planet beyond Pluto has been reported by Soviet scientists, but its existence has not as yet been confirmed in this country.

The mean distance of the earth from the sun, about 92.9 million miles, is an important astronomical distance measuring unit. The astronomical unit is not yet a precise unit because it has not been accurately calculated in terms of miles. Certain refinements in measurements will have to be made before it will be possible to hit the moon or the planets accurately or make close orbits of these bodies simply from calculations of trajectories.

Space research not only has lead to a reexamination of the above basic astronomical unit but also has stimulated the study of astronomy in general. Significant findings are being made through the use of the recently developed radio telescope, which is considered an adjunct to the optical telescope. Radio astronomy has, for example, made it possible to study both the surface and some of the subsurface of the moon. Radio waves from Venus may establish that planet's rotation period, which is unknown at present. Studies of radio waves from the sun may give further information about the activity there and how this is related to still mysterious phenomena on the earth.

The Sun

Besides being the center about which the planets rotate, the sun is the center of our planetary system in another sense. It is the source of almost all light, heat, and other energy for all the planets. All usable forms of energy on the earth, except for nuclear energy, are derived by man either directly or indirectly from the sun. While the sun generates tremendous energy, having a surface temperature of about 11,000° F., it is only a medium-small star compared to other stars. Considered as a star, it is the only star in the universe that is near enough to be studied. All the others are so far away that they appear only as points of light in the largest telescope.

Even though relatively insignificant in the universe, the sun is 864,000 miles in diameter. Its volume is 1⅓ million times that of the earth and its mass ⅓ million times as great. Its mass represents 99.86 percent of the mass of the system. As a result of its mass and central location, the center of mass for the solar system is not far from the sun's center and the sun exerts almost all of the gravitational forces within the system, even though man on earth is mostly aware of only the earth's gravitational force.

Dark spots on the sun, appearing and disappearing periodically, and which are associated with radio and magnetic disturbances on the earth, are prominent features for study. An associated sun phenomenon consists of outbursts of charged particles, known as solar flares. During these flares, which have been studied by rockoons (rockets launched from balloons), ionization of the earth's atmosphere occurs at upper levels with varying effects.

Inner Planets

The four planets closest to the sun, referred to as the inner planets, are Mercury, Venus, Earth, and Mars. Naturally the two planets closest to the Earth, Mars and Venus, have the most immediate interest in planetary space research. The National Aeronautics and Space Administration plans to orbit them and make studies of them within the near future.

Mercury is the planet closest to the sun and it is difficult to observe. For this reason our knowledge of it is less accurate than that of some of the other planets. Its surface is probably rocky and similar to that of the earth's moon, and it is more than half again as large as the moon. Mercury is lifeless, airless, and extremely slow of rotation, its period of rotation being the same as its period of revolution. The planet keeps the same side turned toward the sun, and the differences in temperature between the sunny side and the dark side are extreme. Radiometric measurements indicate that the temperature on the sunlit side is as high as 770° F. Conjecture is made that Mercury was once a moon of the planet Venus.

The next planet is Venus, which is familiar to earth-dwellers as the morning and evening star. Venus is only 26 million miles from the earth when closest, and this is the closest approach of any planet; nevertheless, less is known about Venus than Mercury. Even the largest telescope fails to reveal any permanent or well-defined markings. Astronomers have seen only the dense and turbulent cloud cover. Spectrum analyses of the light reflected from the upper reaches of its clouds indicate that the atmosphere there contains no free oxygen or water vapor, only an abundance of carbon dioxide. The period of rotation for Venus is not known. It may be about a month.

In order of distance from the sun, the next planet is the earth. Since men view the entire solar system from positions on the earth, they often do not assign the earth-planet its proper place or importance in the system. If there were intelligent beings on the neighboring planets, they would see the earth merely as a bright point of light. Through the cloud cover they would probably try to discern evidence of the presence of intelligent earth beings, and they would be perplexed by the prominent markings such as the outlines of land masses on the planet. So far as is known, no other planet has oceans of water. The earth's one satellite, the moon, is described later in connection with possibilities of traveling there (Fig. 124).

Beyond the earth is Mars, which has caused more speculation than any other planet, because it was once belived to be inhabited. In 1877, in Italy, Schiaparelli reported dark-line markings on the planet, that he called canali,

or clefts. Canali was translated as canals in English, and markings on the planet as reported by others were for some time interpreted as a network of canals constructed by intelligent beings. Astronomers have long discarded the canal idea. As to the possibility of the presence of intelligent beings, evidence revealed by the spectroscope shows that there is too little free oxygen, if any in the atmosphere to support human or animal life as known on the earth.

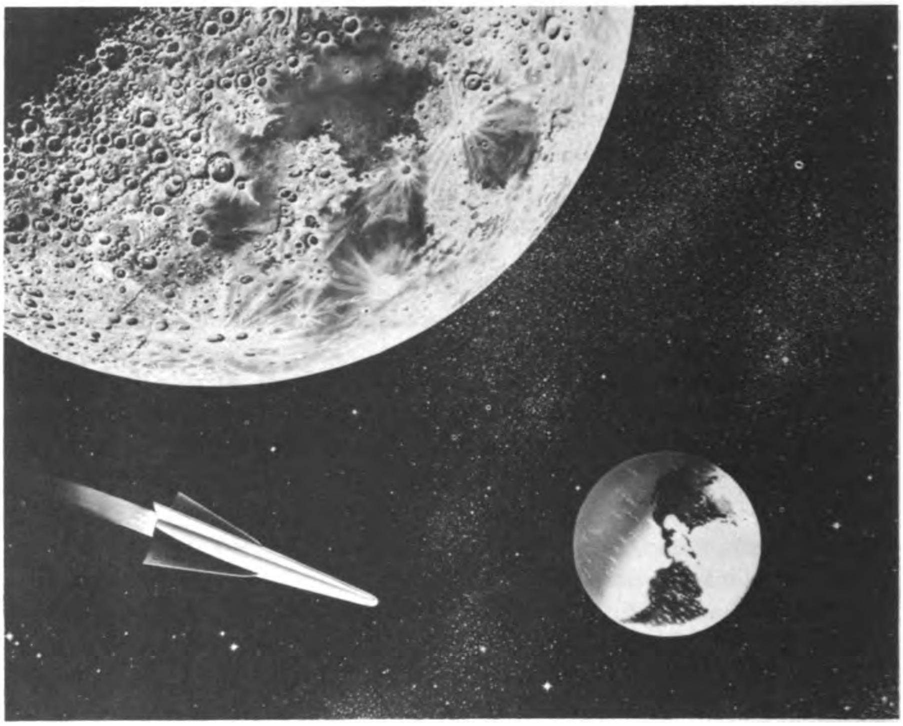


FIGURE 124. A conception of a lunar journey.

Although human beings could not survive on Mars without modifying the environment extensively, it is possible that a self-sustaining colony could be established there. The atmosphere is dense enough to protect the surface of the planet from the bombardment of meteors and from considerable radiation.

Mars has been observed and mapped for more than 275 years, and its surface features can be viewed more clearly than those of any other planet, but they cannot be studied in any detail. When the planet comes closest to the earth, it is still about 35 million miles away. The telescope shows that about three-fifths of Mars has a uniformly orange-red hue. White ice or frost caps alternately grow and decline in size around the poles as the seasons change. The caps may be only an inch to several inches in thickness, as they melt rapidly. When an ice cap thaws, the region around it and towards the equator darkens, and the dark

areas are interpreted as vegetable growth of some sort. The apparent vegetation, thought to be lichenlike plants or hardy mosses, shows up in the telescope as an intense green or blue-green that gradually changes to brown with a change in season. The evidence that there is vegetation on Mars is brought out by the spectrograph, which shows carbon-hydrogen molecules, which are characteristic of vegetation. The atmosphere of Mars is made up largely of nitrogen. There is some carbon dioxide present and probably some argon. Water appears to be stored chiefly in the polar caps.

Mars has a diameter halfway between that of the earth and the moon. Its period of rotation is slightly longer than that of the earth, and its seasons are nearly twice as long. Like the earth, Mars presents its poles alternately to the sun.

Mars has two tiny satellites, named Phobos and Deimos (Fear and Panic). The first is about 10 miles across and the second about 5 miles across. These satellites might be used as stations from which to observe Mars.

Outer Planets

The first four outer planets, the giants (in order from the sun: Jupiter, Saturn, Uranus, and Neptune) are massive bodies of low density and large diameters, which rotate rapidly. On the basis of spectral information, they are believed to have small, dense rocky cores surrounded by thick shells of ice and covered by thousands of miles of compressed hydrogen and helium. Some methane and ammonia are also known to be present. The temperatures on the visible upper atmospheric surfaces range from −200° F. to −300° F. Neptune, the outermost of these four giant planets has a period of revolution of about 165 years.

Jupiter has 12 moons, several of the outer ones rotating in the opposite direction from the inner ones and from the planet itself. Saturn has nine satellites and a set of meteoritic rings. Uranus has five satellites, and Neptune two. The planet Pluto may be a satellite that has escaped from Neptune.

Pluto is 39 times as far from the sun as the earth is. It has a small radius and a mass smaller than that of the earth. It behaves in an odd manner in orbit. The perturbations of Pluto and Neptune suggest that there is another planet beyond Pluto, at a distance of about 7 billion miles from the sun. The temperature of Pluto is about −400° F.

Asteroids

Besides the planets and their moons, there is a group of fairly large heavenly bodies known as asteroids. These are believed to be the shattered remains of one or more planets. Asteroids are concentrated in the region between the orbits of Mars and Jupiter. Except for Vesta, they are not visible to the naked eye. They vary in size from less than 1 mile to at least 480 miles in diameter. From time to time asteroids come within a few million miles of the earth.

Meteoroids

The earth receives much material from space in the form of meteoritic particles. Information about the amount of such material coming to the earth daily is uncertain, and estimates vary greatly. The smallest dust particles are concentrated for the most part in the ecliptic, or the plane of the earth's orbit. This dust probably comes from waste set free when asteroids collide.

The Solar System as Part of the Universe

No study of the solar system, however brief, would be complete without considering the system as part of the universe. As pointed out before, the sun is a star. It belongs to a galaxy of stars, the most readily apparent feature of which is the Milky Way. The star nearest the sun is Proxima Centauri, which is about 4.2 light years away from the earth, so far away that light from the star, which like all light travels at about 186,300 miles per second, takes 4.2 years to reach the earth. The sun is not the center of its galaxy. It is, in fact, some 26,000 light years away from the center. This gives one some idea of the vastness of that galaxy, which consists of about 2 trillion stars. Perhaps as many as 12 percent of them may have planetary systems like our own. Beyond the galaxy of which our sun is a member are other galaxies whose distances can only be described as remote and very much more remote. Telescopes today receive light from distant galaxies that was emitted before dinosaurs roamed the earth, or even before there was any kind of life on earth. After one has tried to conceive of a universe with such staggering dimensions, the distances involved in travel from the earth to the nearest planets seem relatively small, and a trip to the moon appears quite plausible, especially now that artificial satellites have become a reality.

ARTIFICIAL SATELLITES

Considering a tiny artificial satellite against the background of the solar system presents one viewpoint of its significance. There is another viewpoint, based on its usefulness to man. For example, by giving the earth another moon, an exceedingly small one close by, man has been able to make his first direct check on the laws of Kepler and Newton. He was, in a sense, able to substitute direct methods of observation for indirect methods and to obtain a means for refining his calculations. To the meteorologist and the geophysicist, artificial satellites present the opportunity of "seeing" the earth from a distance heretofore impossible. To the space scientist, an artificial satellite represents vast refinements over the high-altitude balloons and sounding rockets. He thinks of an artificial satellite as a long-lived sounding rocket. To the military expert dealing with aerospace weapon systems, almost any information about space has value. He must know many things about the upper atmosphere before he can build and fly higher performance aircraft, before he can develop communications and guidance for missiles, and before he can map the jet streams and other features of the upper atmosphere for navigation purposes.

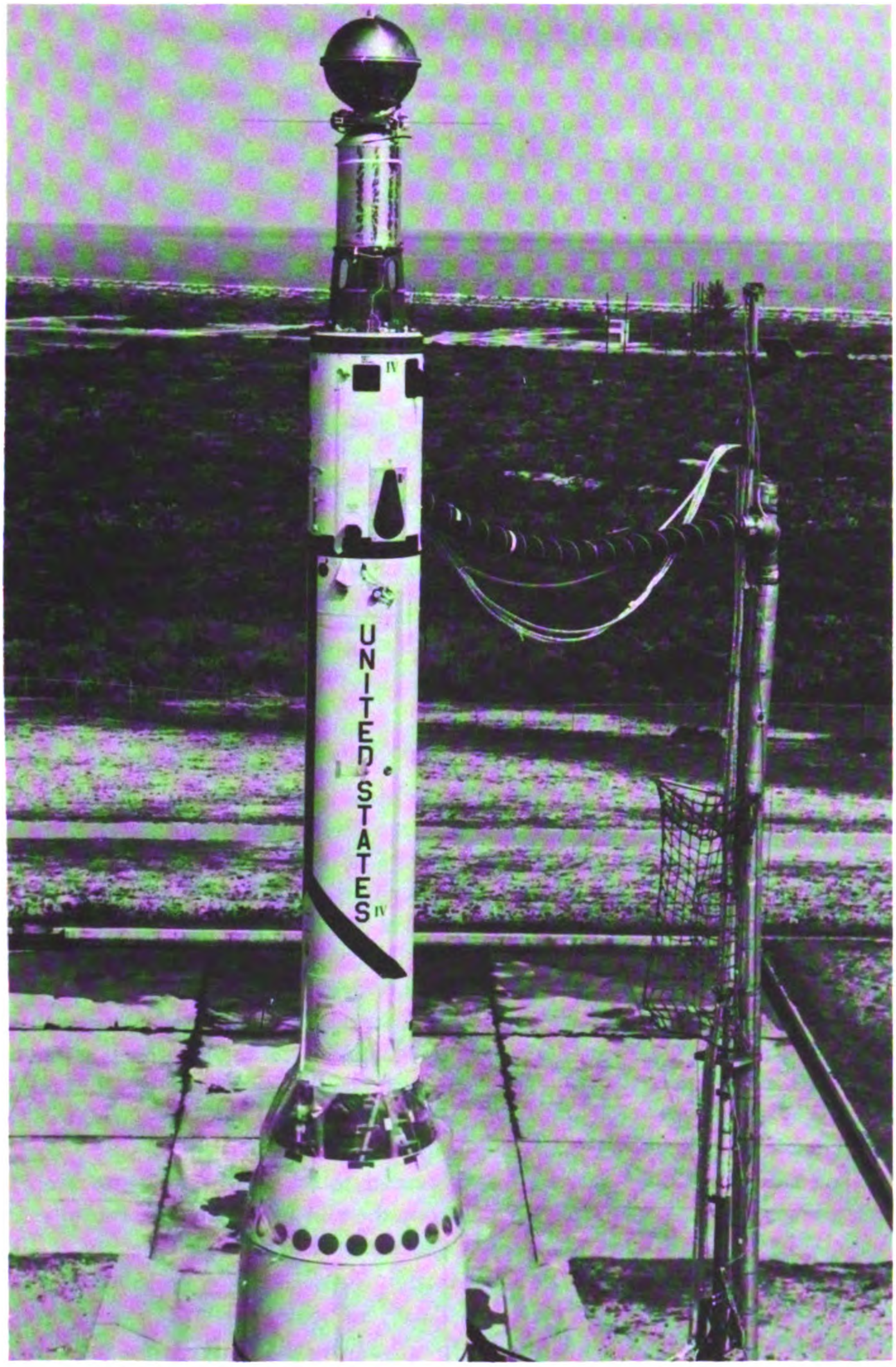


FIGURE 125. Second and third stages of the launch vehicle for project "Echo," atop a Thor vehicle.

Even the simplest observations and calculations made from the first satellites, such as orbital periods at different altitudes and the effects of gravity, were of inestimable value. As the first data were computed and interpreted, valuable information was obtained for launching new satellites. As more and more satellites are launched, data can be further extended and refined. The first satellites could report data only by means of radio and telemetering equipment. As the satellites have become larger, some of them have been fitted with television cameras and capsule-returnable film packets.

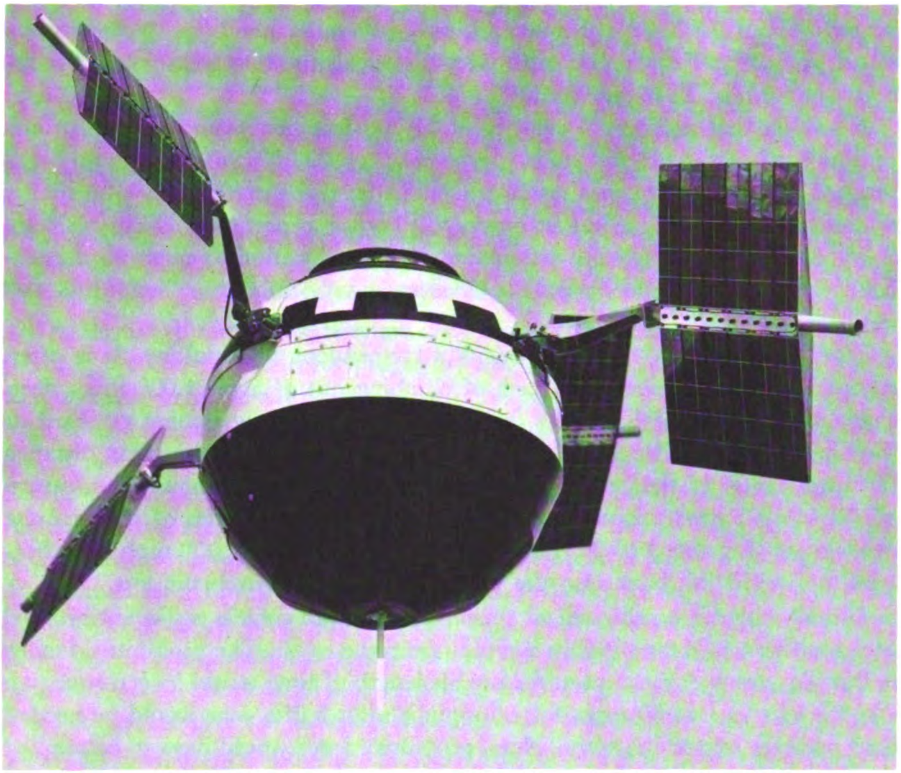
Today, most satellite launchings are parts of larger programs (Fig. 125). In the step-by-step progression necessary to acquire increasingly more valuable information about space, the spectacular achievement is not always the most significant one from the scientific viewpoint. A rigid selection is made in scheduling each satellite launching because of the vast resources required. To send 1 pound of payload into orbit, up to 1,000 pounds of initial weight may be lifted, and this represents a tremendous expenditure of fuel. When a missile fails to send a payload into orbit, a backup is not always provided. In such a case the satellite launching is generally assigned to the next missile scheduled for firing, and the entire program must be moved back one step.

Before considering some of the different artificial satellites that have been successfully launched and the purposes they have served, it would be well to survey problems involved in orbiting and tracking a satellite, and to learn more about the nature of the elliptic orbit, since a satellite is described chiefly in terms of its orbit.

Orbital and Escape Velocities

Placing artificial satellites into orbit requires a multitude of considerations before the attempt, and must reckon with multiple chances for mishap or malfuction. The requirement of proper velocity is only one consideration, albeit important. Orbiting velocity is about six times that of a projectile fired from a piece of heavy artillery. Until the rocket research period underway since World War II began, such vehicle velocity could not be produced. Use of multiple rocket stages is necessary. That is, a first stage rocket raises all stages until its fuel is exhausted, whereupon it separates from the remaining rockets and payload. The fuel in each successive stage ignites a suitable interval after the previous stage has separated. A last stage of power gives the payload impetus and needed velocity in the desired direction. The number of stages, or boosters, used depends upon the design of the missile.

The actual velocity that must be imparted to an earth satellite to keep it from falling back to the earth depends upon the altitude at which it is projected into orbit. The velocity for orbital flight around the earth with a perigee of 100 miles (nearest point to earth) varies roughly from 4.9 statute miles per second to 6.9 statute miles per second. The lower velocity represents the so-called first cosmic or circular velocity (the speed at which a body would orbit in a circle). If a satellite is to travel in an elliptical orbit varying from 100 to a few hundred miles above the earth, its orbital velocity must be between 17,000



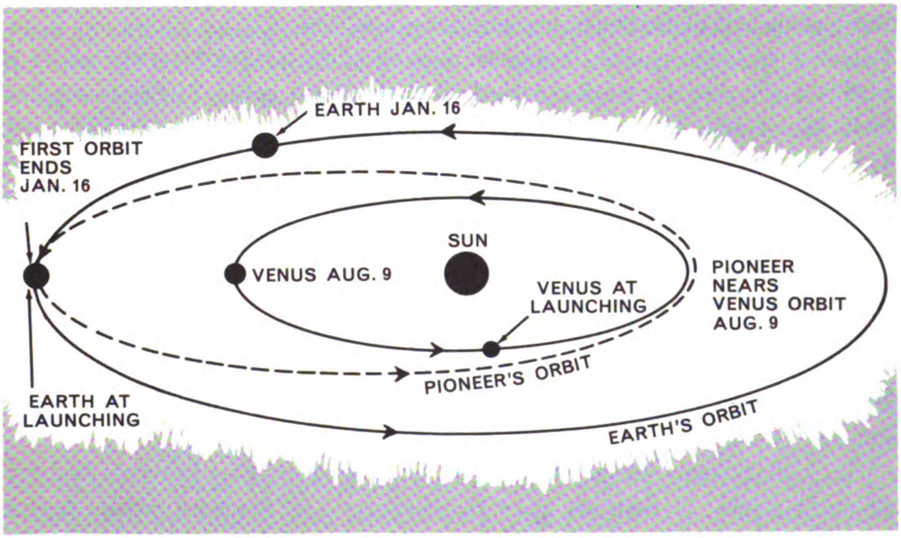


FIGURE 126. The Pioneer V paddle wheel in its first orbit after launching on March 11, 1960. The 90-lb. deep space probe transmitted data more than 20 million miles from its 5-watt transmitter.

and 25,000 miles per hour. At the moon's distance from the earth, it would be only about 3,300 feet per second, or 2,250 miles per hour. No energy is saved by having the satellite orbit at a higher altitude, as more energy is required to lift it to the higher altitude.

A vehicle that achieves a velocity of 36,700 feet per second at the surface of the earth (roughly 6.9 miles per second or 25,000 miles per hour) has reached escape velocity, and it will travel out from the earth in an orbit that is no longer a closed ellipse but an open orbit known as parabola. Escape velocity is, by definition, the velocity required at a given location to establish a parabolic orbit. Escape velocity essentially separates "local" from "long-distance" space travel.

Escaping from the earth represents a tremendous undertaking. It is often compared with the mammoth task of climbing out of a pit 4,000 miles deep that has sides perpendicular at the bottom but gradually sloping outward as the top is reached. The 4,000-mile depth is roughly equal to the mean distance from the center of the earth to the surface (3,960 miles), which is a measure of the earth's gravitational pull. To surmount the steep sides of the pit, one needs a starting speed of 36,700 feet per second (about 25,000 mph.). Otherwise, he would fall back into the pit before he could reach the top.

Actually there is no theoretical reason why a space vehicle could not proceed at a good safe elevator speed in escaping from the earth. The prohibitive factors in this idea are two. First, an unreasonable length of time would be consumed on a space journey—at 60 mph, for example, almost half a year would be needed for a one-way trip to the moon. Next, propulsive force would have to be applied every inch of the way that the earth exerts a predominant gravitational pull. Therefore, a large propulsive force, applied in the initial minutes of a journey, is the only practical method of space rocket propulsion.

Once a body has reached the velocity required for escape from the earth, it continues to move out from the earth even though it gradually begins to slow down. However, a point is never reached when it begins to fall back to the earth. According to Newton's law, the gravitational pull between masses—satellite and all natural bodies in this case—is inversely proportional to the square of the distance between them. As the body gets farther and farther from the earth, its gravitational pull decreases, but, theoretically at least, it never reaches zero. What happens is that the gravitational pull of the sun or that of some other body eventually becomes strong enough to override that of the earth. Then the escaped body may achieve an independent orbit around the sun, as the United States satellites Pioneer IV and V (Fig. 126) have done, or it may be attracted to another planet or a planet's satellite, and orbit about it.

The velocity required for escaping from a planet or other heavenly body in this sense varies. It depends upon two factors: (1) the mass of the captor heavenly body, and (2) the distance from the center of the vehicle to the center of the captor—the body holding the vehicle by gravitational force. The surface escape velocities for the four inner planets and the moon are as follows:

	Feet per second
Mercury	13, 600
Venus	33, 600
Earth	36, 700
Moon	7, 800
Mars	16, 700

Figures are not given for the four giant planets because they would be meaningless; no one knows where the solid surfaces of these planets are located below the thousands of miles of dense atmospheric gases.

Orbits and Trajectories

The terms orbit and trajectory are used in discussing space flight paths. "Trajectory" is commonly used for projectiles and suggests that the path is limited; that is, has clearly defined beginning and end points. The term orbit is generally used to describe the more extended paths of natural celestial bodies and man-made satellites after power cutoff.

One way to achieve orbit of an earth satellite is by impelling the satellite into highly rarefied atmosphere or space, then having it change direction to move approximately parallel to the earth's surface below at a velocity within certain upper and lower limits. The moving object, following power cutoff, will then be in a freely falling state, but its velocity will be such that the curve described in its fall will maintain the vehicle above the earth's surface at distances, or altitudes, within the definite limits resulting from an elliptical flight path.

Four types of orbits of artificial satellites have been named: circular, elliptic, parabolic, and hyperbolic (Fig. 127). If a satellite orbits the earth in such a way that its path follows closely the curvature of the earth (a near circle), the satellite is in a circular orbit. The situation might be compared with what happens when an object is swung around at the end of a string. The string (gravitation) balances the centrifugal force and keeps the object from flying away. If enough speed is given to the object to break the string, the object will fly off tangentially. If enough velocity is given to a body orbiting the earth, it will assume a parabolic or hyperbolic orbit and escape from the earth.

The four kinds of orbits can be described in terms of conic sections. Newton showed that bodies influenced by central masses move in paths which can be duplicated by conic sections, the shape of the section depending upon the velocity of the body. All other things being equal, a circle represents relatively low velocity, an ellipse higher velocity, a parabola still higher velocity, and a hyperbola the highest velocity. True circular and parabolic orbits are rarely if ever achieved, as each represents only one specific velocity, or a borderline condition. Actually the space scientist is primarily concerned with two kinds of orbits: the elliptic and the hyperbolic. In describing natural bodies or artificial satellites in a stable orbit around any body in the solar system, he is concerned mainly with the elliptic orbit, since a body with a hyperbolic orbit would have escaped from the parent body.

The point where the satellite in elliptical orbit comes closest to the earth is known as the perigee; the point where it is farthest away, the apogee. In the

future, satellites will probably be given increasingly higher velocities so that they will move along elliptic orbits that are more and more elongated.

The part of the orbit that is particularly critical for most satellites is the perigee, because here the satellite may dip into the atmosphere and encounter air drag. An artificial satellite is not likely to have an unlimited life unless it travels its complete orbit in airless space. If it does not, every encounter with air resistance takes its toll. Gradually the satellite's orbit begins to shorten and its altitude drops. Finally, the satellite spirals toward the earth to be burned in the atmosphere. Estimates now made as to the possible life of satellites in orbits at different altitudes very greatly. As more data are collected, it will probably be possible to predict the life of a satellite with a fairly high degree of accuracy.

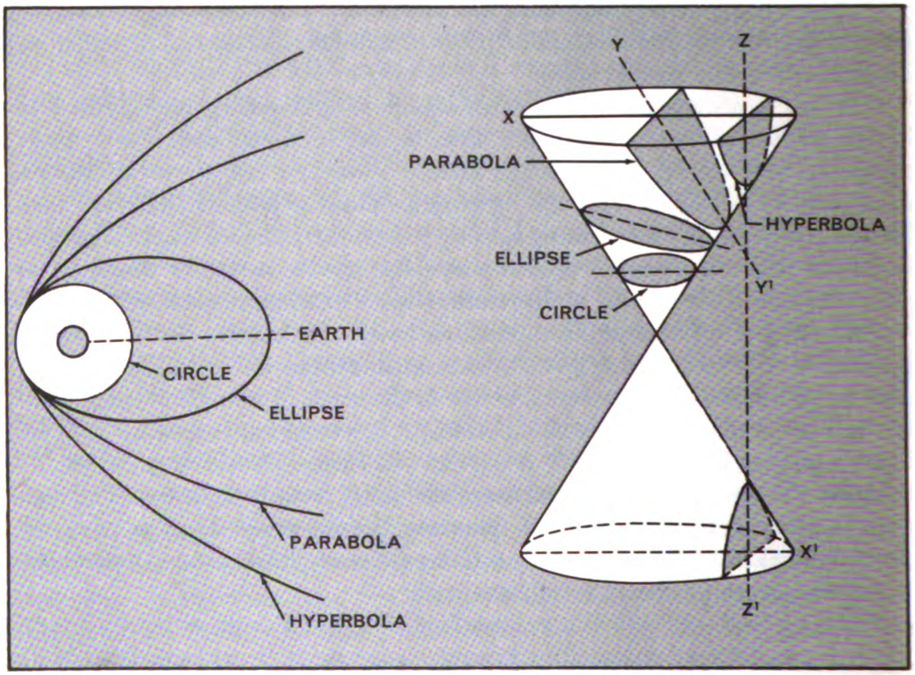


FIGURE 127. The circle, ellipse, parabola and hyperbola and their derivation from conic sections.

Other main features of the orbit of an earth satellite are the period of revolution and orbital velocity of the satellite. The satellite's velocity varies continually as it travels along an elliptic orbit. Velocity is highest at perigee. Here the satellite has more than enough velocity to resist the gravitational pull of the earth, and it begins an upward climb to get away from the earth. Gravitation pull gradually slows the satellite and forces it to stay in elliptical orbit. Velocity decreases until it reaches the lowest velocity at apogee. From this point the satellite begins again to travel closer to the gravitational center of the earth, and its

velocity gradually increases until it again reaches its highest velocity point at perigee. Here the process begins all over again.

To calculate what the changes in the orbital speed of an artificial satellite will be and in this way to help predict its position at a particular time, Kepler's second law, also called the area law, is used. This law states that the radius vector (in this case an imaginary line joining the artificial satellite and the earth) sweeps over equal plane areas in equal periods of time.

From Kepler's third law, the harmonic law, either the distance of the satellite from the earth or its period of revolution can be determined provided one of these has been learned from observation. The law states that the square of a planet's (satellite's) time of revolution is proportional to the cube of its mean distance from the sun (the earth).

Both Kepler's and Newton's well known natural laws relating to gravitational and reaction forces are based on what is known as the problem of two bodies; in this case, the earth and the artificial satellite. Since both bodies are, for all practical purposes, at the same distance from the sun, the sun's gravitational pull does not have to be taken into account. Of course, the problem of two bodies is presented here in its simplest possible form. At most other places in interplanetary space, the effect of three bodies must usually be considered (for example, the sun, a planet, and a satellite). A problem of three bodies is very difficult to solve.

Although an earth satellite's orbit represents a fairly simple ellipse expressed in terms of the problem of two bodies, to an observer on the earth the motion of the orbit is highly complex because of the earth's rotation about its axis underneath the satellite and because of perturbations, or local disturbances in the orbit.

Perturbations are caused by the local differences in gravitational pull, such as those resulting from what could be termed the bulges of the earth, resulting from the fact that it is not a perfect sphere, from high mountains, or from the varying gravitational pull of the moon or other heavenly bodies. Perturbations cause minor changes of a satellite's plane of orbit.

Charted on a globe a satellite's orbit may present the appearance of a complex grid. The exact track of the satellite depending on the velocity of the satellite and the angle that the initial orbit makes with the equator; that is, whether it was launched into an equatorial or a polar orbit.

A satellite launched from a point at or near the equator can take advantage of the velocity of the earth's rotation at its highest point (about 1,000 miles per hour). A launching pointed eastward makes it possible to add the velocity of the earth's rotation as a bonus to the velocity achieved by the rocket. Launched eastward at an angle along the meridians, it utilizes this advantage to some considerable degree. (This is one reason why the Atlantic missile launching range was located in the south at Cape Canaveral, Fla., and was oriented in an easterly direction.) If a satellite is launched along one of the meridians so that it crosses over the poles, it is not given this extra velocity, and is consequently less

economical of energy. Such launchings are made, however, because the satellites can "see" over all the populated areas of the earth.

If a satellite is placed in a polar orbit at an altitude of 200 miles, it travels once around the world every 90 minutes. If the same satellite were launched with the same altitude eastward at the equator, its period to an earthly observer would be longer than 90 minutes; if launched westward, it would be less than 90 minutes.

An orbit of particular value is one established at 1,075 miles, which represents the 2-hour orbit proposed by Wernher von Braun for a space station. Some scientists consider this the lower limit for a permanent orbit. Another orbit of interest is that at about 22,000 statute miles (19,371 nautical miles) above the surface of the earth. A satellite at this distance would, if launched on the equator in an easterly direction, have an orbital velocity equal to the speed of the earth's rotation at the equator and hence would appear to stand still in space as observed from the earth. Three equally spaced bodies in this orbit known as the 24-hour orbit, would be valuable as communication satellites. They could relay signals from one point on or near the earth's surface to another.

Tracking and Observing Artificial Satellites

To make all the detailed computations for following and predicting the orbit of a satellite and to receive and record data, a network of stations is being set up throughout the world. During 1959 the Space Surveillance System was completed in the United States. It provides a capability for tracking and readout of all satellites, both radiating and silent, as they pass over the country. Information received from the network is fed into centrally located facilities for data reduction. The main control, computing, and cataloguing center for satellites in the United States is the Air Force Space Surveillance Center at Hanscom Field, Mass., which is part of the Electronics Systems Division of the Air Force Systems Command. Into it is tied the Air Force Satellite Test Center, part of the Ballistic Systems Division of the same command, which operates near Sunnyvale, Calif. This is a nerve center for an electronic network that extends around the world and into space itself. Its purpose is to satisfy requirements for the launch, acquisition, and recovery of satellites. The center is linked to instrumentation squadrons in Hawaii, to tracking stations in California and Alaska, and to a launch squadron at Vandenberg Air Force Base, California. Another center for computing orbits is the Vanguard Computing Center in Washington, D.C. Optical data goes to the Smithsonian Center.

The technique used is first to make a preliminary estimate of the orbit and then to refine the estimate as further data becomes available. The centers responsible for computing orbits perform two tasks: they learn enough about the orbit to be able to predict positions for useful periods in the future, and later they derive a more exact orbit, which will give the satellite's history.

It is possible to predict the orbit of a satellite with a high degree of accuracy. For satellites with an orbit such as Vanguard I, predictions can be made for several weeks in advance with an error limit of about 1 mile.

To make it possible to predict orbits with an even higher degree of accuracy, it is necessary to add to knowledge about the distribution of mass in the earth, the density of air in the upper reaches of the atmosphere and the density of micrometeoric material. Satellites provide the best means for studying these areas.

A satellite is catalogued according to the year, followed by a Greek letter designating the order in which the satellite was launched during the year. If necessary, an Arabic number is added to show the number of objects, as, for example, the last stage which achieves orbit, and the nose, or payload, which separates from it. Vanguard I, to illustrate, is 1958 Beta. As more satellites are launched, a more complex system of cataloguing will be necessary.

The three principal types of tracking systems are radio and radar systems, optical systems, and infrared systems.

Much progress has already been made with electronic communication in space. The minitrack and microlock systems have been developed, and radio telescopes with larger antenna surfaces are being built to receive cosmic "noises" and communications from farther out in space. Lunik I, the Soviet satellite, communicated from a distance of 396,000 miles, and the U.S. Pioneer IV from 402,000 miles. With Pioneer V, the larger of its two transmitters was expected to signal from as far out as 50 million miles (about the distance to Venus or Mars when these planets are relatively close to the earth). Because the 150-watt transmitter made too much of a drain on the solar batteries, it was necessary to turn back to the 5-watt transmitter. The smaller transmitter signalled from more than 24 million miles out in space, most of the signals being picked up by the radio telescope at Jodrell Bank, England. In Pioneer V, Explorers VI and VII, and other satellites, the "paddlewheel" technique was successfully used to expose solar cells for powering radio transmitters. The radio signals from the satellites telemeter the recordings of instruments, which are read out at stations on the ground. By a simple process of switching, one radio transmitter in a satellite can send hundreds of instrument readings to ground stations, and millions of miles of space can be covered with relatively low-powered equipment. In Tiros I, pictures taken by two television cameras were recorded on a magnetic tape and then read out at intervals upon command from the ground.

The location of a satellite can be ascertained by conventional radar stations. A doppler radar system can, in addition, tell the aspect and the velocity or acceleration of the satellite. The doppler system is based upon the principle that the shift in the carrier frequency of the return signal is proportional to the velocity with which the satellite approaches the radar station or recedes from it.

One great advantage to radio signals is that they make it possible for the satellite to transmit data even when it is hidden behind a layer of clouds or when it is obscured by the daylight. If the radio signals fail and the satellite becomes silent, visual observation is used.

The farther distant a satellite, the larger the portion of the earth's surface that it can "see" at one particular time, and the longer it can be observed from any point on the earth's surface. A satellite can be seen best by an observer on

earth when it, while reflecting sunlight, is passing overhead in a darkened sky. This occurs twice in 24 hours—just before sunrise or soon after sunset. A team of observers is needed to cover the region of the sky through which a satellite is to pass to insure that it will be spotted.

Optical observation in the United States is organized as Operation Moonwatch under the direction of persons at the Smithsonian Astrophysical Observatory. Some training is needed for observing satellites. Telescopes of short focal length are used so that the rate of displacement is as small as possible. All telescopes are mounted on gimbals to permit rotation about two axes. Tracking is usually done manually, or partially so. A special type of 25-power telescope, known as a theodolite, conveys its horizontal and vertical deflections to magnetic records, once the telescope is pointed at the satellite. A variation of recording telescopes is the cinetheodolite, which produces a photographic record of the satellite with respect to cross hairs in the telescope and gives azimuth and elevation. With information obtained from cinetheodolites at two different positions, it is possible to locate the satellite at a specific time by means of triangulation.

Satellites are sometimes tracked so that information can be recovered from a data capsule, which is another method of transmitting data from a satellite. Whether radio telemetry or recovery by data capsule is used depends upon many factors, such as the volume of information that must be transmitted, its timeliness, and the rate at which it must be supplied.

Uses of Satellites

Until the launching of Transit I–B, the program for artificial satellites represented an extension of the program for probing the atmosphere with sounding rockets. A rocket that goes out to a distance of not more than one earth radius (about 3,960 miles) and falls back to the earth is considered a sounding rocket. Rockets sent out beyond this distance are known as space probes. Satellites launched by rockets can stay aloft for weeks, months, years, or even indefinitely continuously sampling their environment and, for an extended time at least, transmitting the information back to the earth. Instruments in satellites record a variety of information such as the density of the air at extremely high altitudes, ultraviolet radiations from the sun, cosmic rays, the cloud cover of the earth, radiation belts, micrometeoritic dust, the temperatures on the skin of the satellite, the earth's magnetic field, ionization, and propagation of radio waves of various frequencies. Such a vast amount of basic information has already been obtained from satellites that complete analysis lags behind by several years. Rocket and satellite flights have already improved knowledge of the ionosphere. The intent is to collect enough data to chart the regions about the earth out to a distance of about ten earth diameters (about 79,200 miles). Such information will be useful both in advancing general basic space knowledge and to the Air Force in developing its weapon systems.

The early satellites were experimental in nature. The United States now has

some projects to develop satellites for specific purposes, such as for meteorology (Tiros), navigation (Transit), communications (Courier, Echo, Steer, and Advent), and reconnaissance (Samos and Midas).

The first U.S. satellite, Explorer I, which was launched soon after Sputnik I, brought to light the existence of the first of the Van Allen radiation belts.[1] Three other Explorer satellites (III, VI, and VII) were launched by October 1959 as combined scientific and meteorological satellites. They, as well as the Pioneer and Discoverer satellites, provided the data establishing the Van Allen belts. Explorer VI telemetered a crude picture of cloud cover, and it also provided additional data on the structure of the Van Allen radiation belts and of the nature of the particles composing them.

Vanguard I was the second U.S. satellite launched into orbit. It measured aspects of the earth and discovered it to be a trifle pear-shaped. The tendency toward this shape is important to measure. Correct measure, for example, can make cartography (mapmaking) more accurate, and gravitational effects on satellites more predictable. Project Vanguard was begun especially for orbiting satellites, and a rocket was developed for the purpose (Fig. 128). After four Vanguard satellites were put into orbit, the project was discontinued, but not before information was accumulated that was useful in launching subsequent satellites. The radio of Vanguard I, powered by solar cells, was still "beeping" some years after it had been put into orbit, and it may continue to do so for centuries. The satellite itself should stay in orbit for at least 200 more years and perhaps for as much as 1,000 or 2,000 years. After the satellite had been in orbit for about 2 years, scientists made the amazing discovery that it was being "blown off" its course by sunlight. That is, sunlight exerts pressure (sometimes referred to as photon pressure); this small but cumulative force was having a measurable effect upon the orbit of the satellite.

In the fall of 1958 the United States began its space probes by launching the first Pioneer satellite. By April 1960, four Pioneer satellites (I, III, IV, and V) had been put in orbit, with results as follows:

Satellite	*Results*
Pioneer I	Insufficient velocity to reach vicinity of moon but valuable information received on space radiation.
Pioneer III	Insufficient velocity to reach vicinity of moon but valuable information received on space radiation during 38-hour flight.
Pioneer IV	Passed within 37,000 miles of the moon and radioed back data on space radiation; communications received from 402,000 miles; went into solar orbit.
Pioneer V	Valuable information received on temperature, micrometeorite impacts, radiation, and magnetic fields; long-distance record on communications; went into solar orbit.

[1] Doughnut-shaped belts of high-energy charged particles trapped in the earth's magnetic field, which surround the earth.

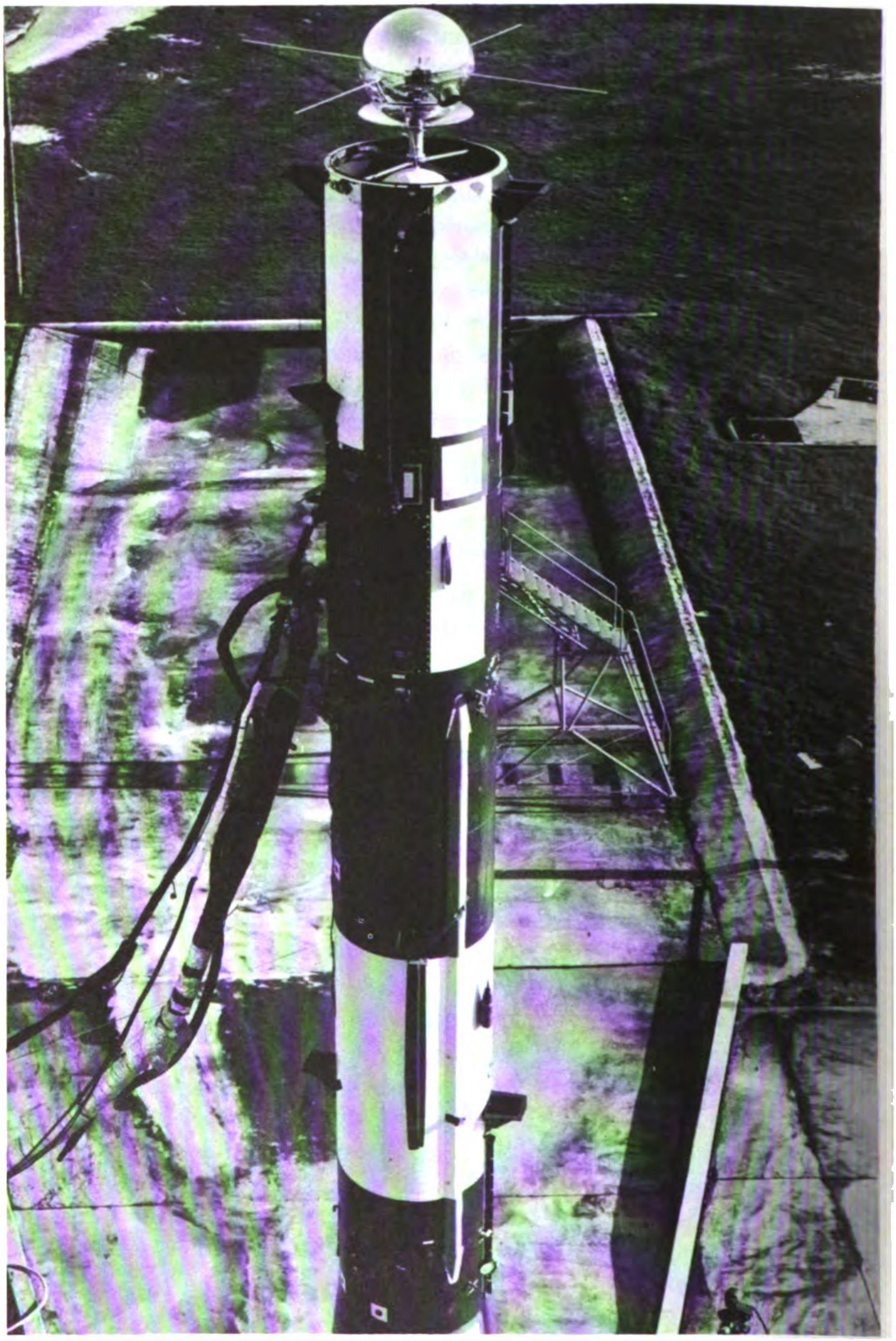


FIGURE 128. Vanguard II rests atop satellite launching vehicle before protective nose cone is added.

In December 1958, Atlas, the "talking satellite," transmitted President Eisenhower's Christmas message to the world, showing that it was possible to store a message in a satellite and transmit it later. The satellite contained a delayed repeater system. As a follow-on to Project Score, under which Atlas was launched, Project Courier was set up and assigned to the Army. Under the project the Army is studying means for linking satellite communications and ground communications. Closely allied with Project Courier is Project Echo, conducted by the National Aeronautics and Space Administration for launching into orbit 100-foot inflatable balloons. The balloons, made of mylar plastic coated with aluminum, are designed for reflecting back to earth high frequency radio waves originating on the earth. These waves, traveling only in straight lines, cannot otherwise reach their destinations because the curvature of the earth interferes. In August 1960, Echo I, the first balloon satellite, was successfully launched into an orbit 1,000 miles above the earth, and radio waves relayed to it from widespread points on the earth were received with remarkable clarity. Radio signals had already been bounced off Tiros I and other earth satellites in orbit. Two more recent communication projects are Steer and Advent. Project Steer is designed to relay messages to aircraft in the arctic region through satellites in polar orbit. Project Advent is intended to design or put satellites

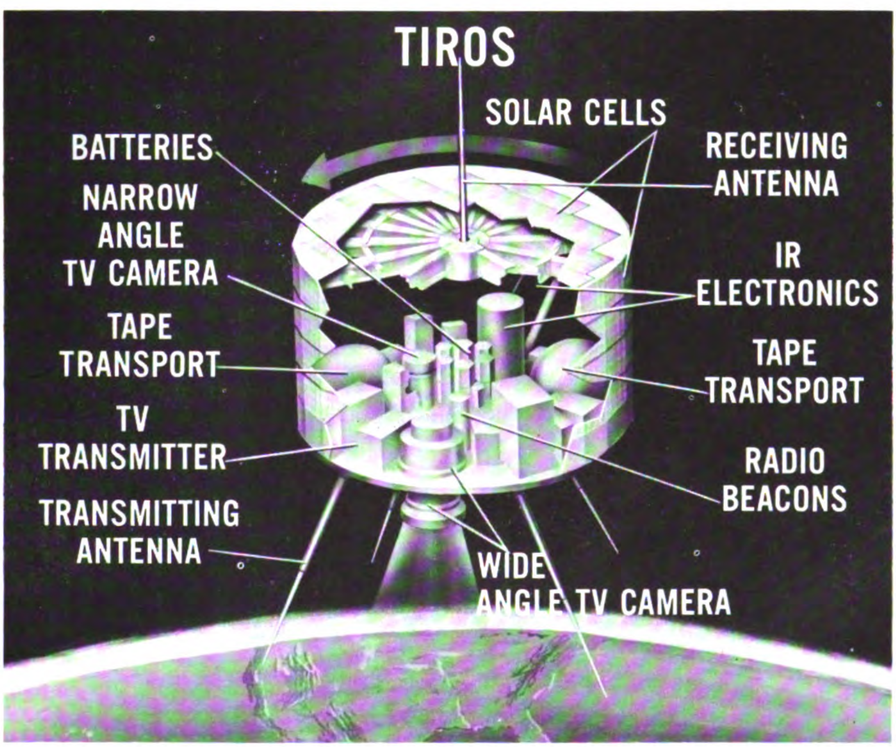


FIGURE 129. A cutaway drawing of Tiros.

in the 24-hour orbit at an altitude of about 22,000 miles above the earth, where they would seem to be stationary.

Project Discoverer has successfully launched many satellites, all intended to determine stabilization methods, perform biological experiments, and secure data on the escape and recovery of a capsule. Although a capsule had been successfully ejected several times, it was not until August 1960 that a capsule was recovered, from Discoverer XIII. As far as is known, this was the first manmade object ever recovered from orbit. Later in the same month a C–119 equipped with a snare arrangement caught the capsule from Discoverer XIV in midair. The Discoverer satellites were the first to achieve a polar orbit, the first to be controlled in orbit, and the first to eject a capsule in orbit. They were the first U.S. satellites to carry a payload of more than 300 pounds.

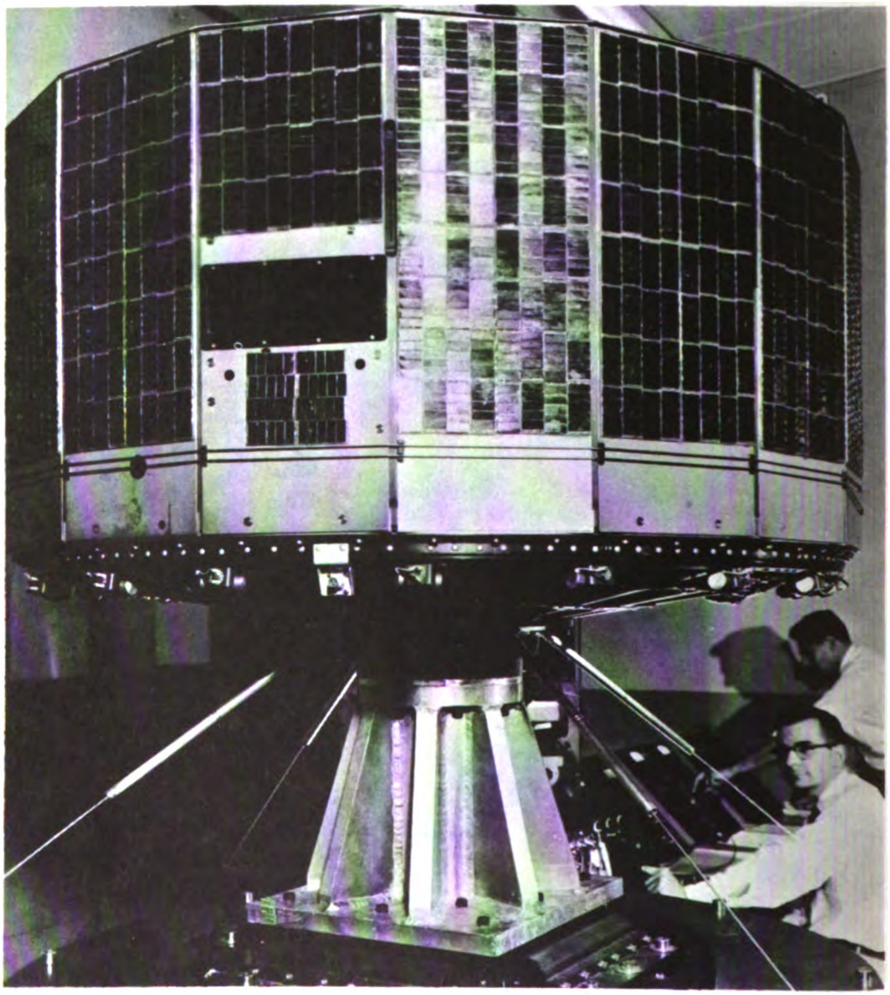


FIGURE 130. Tiros I, meteorological satellite, undergoes tests.

Tiros I, launched in April 1960, was an experimental satellite for recording meteorological data by using two television cameras (Figs. 129 and 130). During its useful life of 78 days, Tiros I took 23,000 pictures of cloud cover. The television cameras snapped two pictures per minute, which amounted to 32 pictures to cover a strip of earth 3,500 miles in length. The pictures were stored on a magnetic tape and were later read out to stations on the ground. After the tape transmitted its recording, it was automaically wiped clean and prepared for another recording. Surpising results were obtained with the pictures. Soon after the satellite was launched, it accurately located the eye of a hurricane near Melbourne, Australia. Photographs taken from high altitudes open an immense perspective in the study of the earth, as they enable one to see it as a whole, perceiving relationships, functions, and terrain features as only they can be viewed from a distance.

Transit I–B, an experimental satellite also put into orbit in April 1960, was the first satellite successfully launched in Project Transit, which is designed to develop navigation satellites to guide ships and aircraft by means of frequency signals. Transit I–B covered the world and could be used in any kind of weather day or night. The doppler effect—measurable change of frequency as the sender and receiver move apart or away from each other—is utilized with these satellites to provide navigational fixes. Transit II–A, the second research satellite under Project Transit to go into orbit, is an advanced model of Transit I–B. It was launched with a smaller satellite for measuring radiation carried on top of it. This was the first dual launching. The satellites were separated in orbit. The first two transit research satellites followed different courses. The plan is to have eventually four navigation satellites in evenly spaced orbits around the earth, sending out distinctive radio signals. By tuning in on the signals, a navigator could determine his position much more accurately than at present. Under the present method of sighting stars, accuracy can be obtained within a half mile or a mile. When the transit system is operating, a navigator should be able to determine positions accurately within one-tenth of a mile.

In June 1960, Midas II was successfully launched as part of Project Midas (Missile Defense Alarm System). The satellite, which weighed 8,600 pounds, carried an infrared heat-seeking sensor in the nose. The sensor is intended to detect ballistic missiles when they are fired.

At the same time that the United States was making steady step-by-step progress with its satellite program, the Soviet Union was launching fewer but more spectacular satellites. As is well known, the first artificial satellite ever to be launched was Sputnik I, sent into orbit in October 1957. It weighed 184 pounds and transmitted information on temperatures, cosmic-ray radiations, the incidence of meteorites, and air density. It remained in orbit about 3 weeks. Sputnik II, which weighed six times as much as Sputnik I, carried the dog Laika. Data was collected on Laika's breathing, pulse beat, and blood pressure. The dog allegedly died 100 hours after takeoff. Sputnik III carried instruments designed to detect radiation from the Van Allen layer. The fourth Soviet earth satellite was a 4.5-ton space vehicle with a dummy at the controls. The ship was to

descend from orbit upon command and be burned up in the atmosphere. When its retrorocket was fired to slow the ship, however, it fired in the wrong direction, and the ship climbed higher and went into a larger orbit.

The Soviets launched their first moon probe, Lunik I (Mechta), in January 1959. The rocket missed the moon by 4,660 miles and went into an orbit around the sun. Lunik II successfully impacted a payload and a carrier rocket on the moon. Lunik III passed behind the moon, photographing its unseen side. The photographs were sent back to the earth over distances up to 274,000 miles, and the satellite then went into a vastly elongated earth-lunar probe path. The trajectory of Lunik III as announced by the U.S.S.R. was confirmed by the radio telescope at Jodrell Bank, England. While authenticity of the Soviet moon pictures has been questioned, most experts, such as Dr. Gerard P. Kuiper, director of the Yerkes Observatory, do not doubt their validity, although they have been retouched and the amount of detail shown is "infinitesimal" when compared with that of observatory photographs of the moon. The very fact that the pictures could have been taken and transmitted over such vast distances shows that the Soviets have made great forward strides in photography.

In August 1960, the Soviet Union announced that its scientists had successfully brought back two dogs and other living organisms from orbit. It was reported that the space ship that carried them could accommodate two men. On April 12, 1961, the U.S.S.R. announced that it had successfully orbited a man, Major Yuri Gagarin.

On May 5, 1961, U.S. Navy Commander Alan B. Shepard, Jr., piloted a Mercury capsule through space to become America's first astronaut. A Redstone rocket was the vehicle used to lift Commander Shepard in the 3,000-lb. spaceship. The 15 minute flight took him to an altitude of 115 miles and reached a speed of 5,100 miles per hour (Fig. 131).

In the relatively short time since the launching of Sputnik I, much valuable information had been obtained from the satellites sent into orbit by both the United States and the Soviet Union. Scientists have found out more about the earth itself, and they are daily gaining an understanding of the upper reaches of the atmosphere, of cislunar space, and even of the frontiers of interplanetary space. All this information will help to make manned space travel possible.

MAN IN SPACE

When man ventures farther and farther into space, he will have the advantage of all the information that complex electronic equipment has been able to bring to him. He will not be traveling like the voyagers of old on unknown seas. As each step forward is made in space travel, man will chart his course and validate his equipment. But the most significant step forward will be achieved when man can establish himself for significant periods in an observatory in space. Neither complex instruments nor complicated electronic data reduction and computing devices can take the place of the observations made through man's sensory organs and interpreted by his brain.

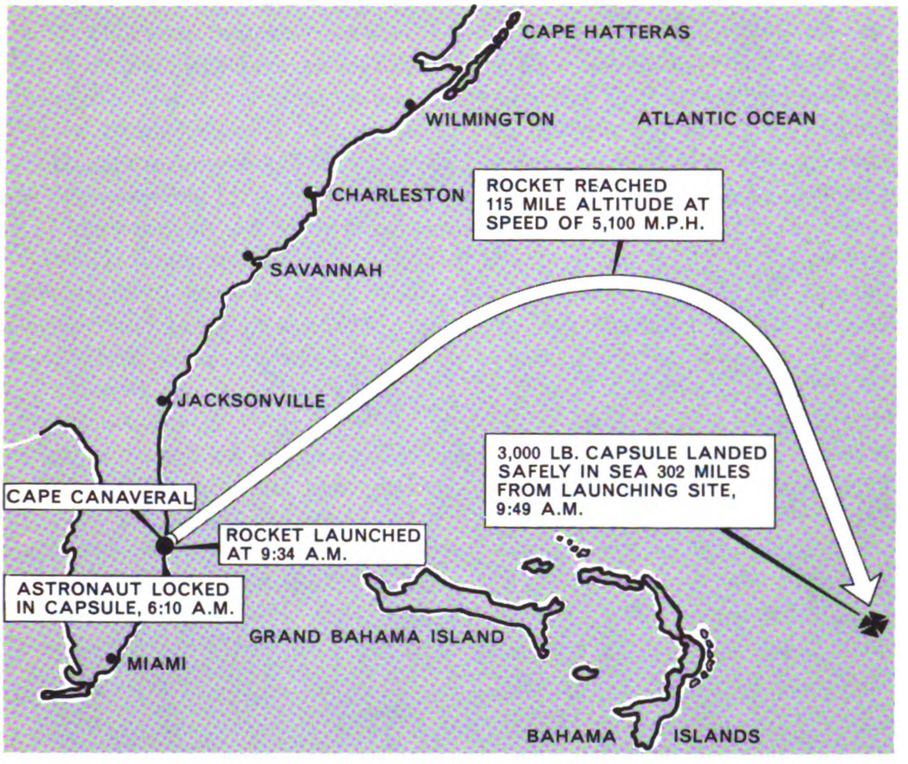


FIGURE 131. Chronological diagram of America's first man-in-space flight by astronaut Alan B. Shepard, Jr., Comdr., U.S. Navy.

Most space scientists and authorities on space medicine, while pointing out the hazards and the factors still unknown, say with assurance that man will be able to extend his flight far beyond the atmosphere.

Many of the problems with which medicine is concerned have long been studied by aeromedical specialists. Years ago they began to study space-equivalent conditions and men flew under such conditions. As early as 1956, for example, the X–2 reached an altitude of nearly 24 miles, and in 1957 Maj. David Simons made studies of the atmosphere in a balloon at about 20 miles. These altitudes are well above space-equivalent conditions, which as far as man's need for oxygen and pressure-breathing apparatus is concerned, begin at about 8 miles. The majority of the basic problems of space medicine are common to those of aviation and have already been investigated by aeromedical specialists. There has been a step-by-step progression from the simple oxygen mask to the full-pressure suit and finally to the space capsule.

As special problems of space medicine became apparent after World War II their study was commenced. The School of Aviation Medicine, now at Brooks Air Force Base, Tex., set up a department of space medicine in February 1949 under the direction of Dr. Hubertus Strughold, a German-born physiologist, who

has become one of the foremost authorities on space medicine. During the same year the Aerospace Medical Laboratory, now part of the Aeronautical Systems Division, made studies with animals in rockets. Problems connected with man's immediate biologic needs in space had to be solved while he was still flying well within the atmosphere. Studies made with centrifuges, rocket-powered sleds, and balloons provided the answers. Besides the studies at the School of Aviation Medicine and at the Aerospace Medical Laboratory, the Air Force is also making studies in space medicine at the Aero-Medical Field Laboratory, Missile Development Center, Air Force Systems Command. The Navy also has considerable aeromedical capabilities, and, in March 1960, the National Aeronautics and Space Administration set up an Office of Life Sciences.

In 1960 all of these medical problems of space flight were being clarified and focused upon the United States' first attempt at putting a man into space—Project Mercury. Under this project, an undertaking of the National Aeronautics and Space Administration in cooperation with the Air Force, the United States began detailed planning to send an astronaut into orbit in a space capsule at an altitude of about 100 miles, the capsule to be recovered after one or more circuits of the globe. Some of the important problems that an astronaut must meet, on "local" trips such as the above or on extended trips into space, are outlined below.

Need for a Closed Environment

Men will have to take with them an environment suitable for their survival and comfort each time they venture into space. The space cabin must be pressurized by gases stored inside, because there will be little or no air on the outside to compress. Constant recovery of oxygen from the gases breathed into the cabin air must go on. Continued oxygen supply is only one of life's necessities. Temperature must be controlled, if not to preserve life, then to keep the occupant tolerably comfortable and to reduce the need for water intake to a minimum. Within the cabin must be stored all the food, water, and oxygen needed, or the means and materials for providing them, for an entire space voyage (Fig. 132).

Biologists think of the space cabin for a flight of long duration as a closed ecological system; that is, a system in which plant and animal life can mutually support each other. The system includes the cycling and processing of air, liquids, and body wastes so that they can be used again. In a test of a sealed capsule made at the Aerospace Medical Laboratory in April 1960 as part of Project Hermes, potassium superoxide was successfully used for recovering oxygen from exhaled carbon dioxide and drinking water was recovered from urine and the water vapor exhaled in breathing.

In a space cabin, plants might be used for completing the recycling of air, since plants take in carbon dioxide and give off oxygen. A tank of fast-growing Chorella algae, similar to pond scum, is usually suggested as best for the purpose, with the further possibility that the algae might be used as food. However, because of weight, algae or biological systems are not feasible for use on anything but the longest duration missions foreseeable in the near future; i.e.,

FIGURE 132. New tube-type feeding is tested for high altitudes of space flight.

missions approaching 1,000 days duration. Experiments conducted by the Army Medical Research and Nutritional Laboratory showed that the solution to the food problem is not so simple, as subjects became nauseated from a steady diet of algae. While use of water-soluble powdered food produced in the laboratory was more palatable, as shown by experiments conducted elsewhere, such use would, of course, be apart from a closed ecological system.

Figures given for man's daily needs for food, water, and oxygen vary greatly. The rations per man for 1 day might weigh as much as 7 to 10 pounds. To this

must be added 2.5 pounds or more oxygen needed for breathing, plus the weight of all the personal equipment and materiel needed to store, process, and support the environment itself. For the Mercury capsule, designed to remain aloft at least 95 minutes—that is, one complete orbit around the earth—tentative computations were made that a total of 2,680 pounds had to be put into orbit. This weight is divided as follows:

	Pounds
Man	150
Personal equipment	330
Environment (capsule)	2, 200
Total	2, 680

Once a cabin is in space, it must be kept sealed. If a meteoroid should puncture the wall, explosive decompression might occur. Under space conditions, the time of useful consciousness would be no more than 15 seconds. In such a case, an automatically inflating emergency pressure suit would extend this time and allow the astronaut to repair the cabin. Another possibility would be to provide the cabin with some means for automatically sealing a puncture in the wall.

One of the big questions is that of the psychological effects on the astronaut confined in a sealed capsule or cabin within the vastness of space. As the psychologists point out, all the whirling in centrifuges and all the sitting in tight, dark rooms and simulated space capsules cannot give all of the answers they need. Until man actually goes into space, one big factor is missing. The subject always knows he is still on earth, and, while he might give reliable physiological data, he cannot give valid answers to the psychologist. It has been shown, however, that complete isolation from incoming light, sound, or touch can produce hallucinations in a period of only 48 hours. Psychologists also point out that an important factor contributing to hallucinations when man is alone in space over prolonged periods, will be a strong feeling of a complete loss of contact with the earth. This is known as the "breakoff" phenomenon.

Many revealing studies in psychology and physiology will be made as space travel progresses. Because of the high and prolonged accelerations and decelerations that will be experienced in space travel, extensive studies have been made of their effects on the human body.

Effects of Acceleration and Deceleration

Travel at enormous velocities is not harmful to man. Indeed, the whole world's population is speeding, in relation to other points, at tremendous velocities as, along with the entire earth, it rotates on the earth's axis at about 1,000 mph at the equator, revolves about the sun at about 66,000 mph and accompanies the entire solar system on its swift path through the cosmos. So, the mere fact that, if man is to escape from the earth and reach interplanetary space, he will have to travel at velocities well over 25,000 mph is not alarming. Only rapid acceleration and deceleration cause bodily harm.

The effects upon the body by reaction to acceleration or deceleration have been studied for many years in experiments on rocket-powered sleds and on centrifuges. These g-forces, as they are called,[2] increase sharply in maneuvers which accelerate or decelerate a body, such as high-speed turns. In such a maneuver, a pilot experiences augmented g-force as the increased pressure of the seat and floor of the aircraft against his body. At 5 g, only slight movements of the arms and head are possible. At 7 g, the blood is about like liquid iron. But forces much higher than 7 g can be endured without permanent harm, when experienced for extremely brief time periods. Lt. Col. John Stapp, of the Wright Air Development Division, endured peak loadings of 45 g for a fraction of a second while he was sitting in a rocket-powered sled. If the body is in a supine or prone position with g forces applied through the body in a transverse direction, it can withstand much higher g forces than if in a sitting or standing position.

The g forces that must be withstood in space flight do not differ from those that have been experienced in aviation except that they could at times be much higher and of longer duration. These high accelerations and decelerations will be experienced either at takeoff or upon reentry, and any time power is used to accelerate or decelerate the vehicle in space.

Calculations as to the amount of acceleration produced by firing a three-stage rocket vary up to about 10 g. Experiments on centrifuges have shown that these forces can be withstood for the time that would be necessary, if the astronaut is subjected to transverse g's in the supine position. Individuals differ greatly in the amount of g force they can withstand. Training with g forces on the centrifuge can increase tolerance. Fear and straining increases tolerance.

Medical specialists with Project Mercury reckoned with a force of 8 to 9 g at exit and reentry, not ruling out the possibility that astronauts might experience as many as 20 g momentarily if the capsule were tugged away from the missile at the time it went into orbit, or if the capsule reentered the atmosphere at the wrong angle. To give the astronaut greatest protection, couches are molded to his body.

Weightlessness

Since the phenomenon of weightlessness, always to be encountered by astronauts unless provision is made to counter it, does not occur naturally anywhere on earth, students of space medicine at first had some misgivings about its effect on the human body. They thought that continued exposure to weightlessness might impair the automatic nervous functions, such as those controlling heart beat, respiration, and digestion.

Medical researchers then found that they could approximate the condition of weightlessness for short periods by flying an aircraft through the so-called weightless Keplerian Trajectory, which is produced by making a dive, a pullup, and

[2] One g of force exerted upon an object by reaction to acceleration or deceleration is equivalent to the force exerted upon an object that is subjected only to gravity. This unit of measurement borrowed its designation "g," of course, from the word "gravity."

then another dive. A zero g force, or weightlessness, is produced during push-over into the second dive. With the C–131B, weightlessness can be produced for periods up to 14 seconds. With the T–33A and the F–94C, it can be produced for periods up to 45 seconds. With the Century series aircraft, weightlessness can be sustained for more than 60 seconds.

During the time that weightlessness exists, unrestrained passengers and solids and liquids may float about the cabin of the aircraft. Repeated experiments produced some positive results: individuals vary greatly in their reactions to weightlessness, and even the same persons show different reactions at different times. Some subjects said that they found the condition of weightlessness exhilarating, and they would be willing to continue the experiment indefinitely. Other subjects became disoriented, suffered nausea, and even felt effects long after they were on the ground again. There were no pathological effects. As training can increase tolerance to g forces, continued exposure to weightlessness helps to accustom one to the condition.

The best answer that can at present be given to the effects of prolonged weightlessness was given by the dog Laika in the Soviet satellite, Sputnik II, who was encased in a specially equipped pressurized cabin. He is alleged to have lived through 100 hours of weightlessness and showed no apparent ill effects.

FIGURE 133. The astronauts practice coordination movement in weightlessness experiment.

This experiment was a follow-on from experiments made with dogs at altitudes up to about 125 miles. The dogs were trained to make the flight and the recovery, and they adapted well to the condition of weightlessness. The two dogs recovered from orbit in Sputnik V were reported in good condition after more than 24 hours of weightlessness in a space vehicle traveling at speeds of 19,000 mph.

When inside a spaceship astronauts may experience difficulty with walking, and be handicapped in eating and drinking if no provision is made to simulate gravitational forces. Ingenious methods advanced for preventing adverse reactions to a prolonged weightless condition in a space cabin include establishment of an artificial gravity by revolving the cabin about a central axis.

A man who orbits above the earth is, in effect, a satellite. Should an astronaut leave his spaceship in a space suit or capsule, he would not "drop off." To move away from the space vehicle, he would need some kind of propulsion. Escape velocity from the vehicle would be very low, and propulsion under these conditions better not be applied unless the astronaut is prepared to cope with the danger of drifting away. He might need to keep moored to his vehicle.

Bombardment by Meteoric Material

Estimates of the possible danger from bombardment by meteoric material in space vary all the way from regarding it as a considerable hazard to pointing out that an occasional meteoroid will strike against the space ship with small likelihood of puncturing it. Meteoric material about the size of a speck of dust can travel at tremendous velocities. Collision with a space vehicle may cause the vaporization of matter at the point of impact; and the vehicle could possibly be punctured if it were not shielded with such a device as a bumper, or a false outer shell. Satellites have been given highly polished exteriors so that impacts with micrometeorites can be registered and impact points seen if satellites are recovered. As another detection device, many satellites are filled with gas at low pressure so that a puncture, permitting gas escape, will provide a means to send information, by telemetering methods, to the ground.

The hazard from meteoric material is not nearly as great as it was originally thought to be, although there is evidence of encounters with micrometeorites. Further tests are continuing at the Langley Research Center of the National Aeronautics and Space Administration to find the effects of bombardment on space vehicles by these small particles.

Harmful Radiation

The magnitude of radiation hazards that could beset astronauts is not completely known. One type of radiation hazard, the Van Allen radiation belts, discovered with the aid of early satellites and still being investigated, are thought to extend from an altitude of about 500 to 52,000 miles into space out from the equator. The belts consist of charged particles that move along the magnetic lines of force, running between the North Pole and the South Pole. Manned satellites could orbit the earth at altitudes low enough to avoid these belts, and

manned space vehicles might either be shielded from them or routed so that they leave and enter through openings at the poles.

Cosmic rays, or particles, the majority apparently originating in the deep reaches of space, travel at very high speeds and with very high energies. In general, they have a tremendous capacity to penetrate. Since cosmic rays are filtered out by the upper atmosphere or are altered by it, they cannot be adequately studied at the earth's surface. On one occasion a balloonist remained aloft in a balloon-supported capsule near an altitude of about 20 miles for approximately 32 hours. Apparently he was not injured by cosmic rays, but some mice carried aloft in this test returned with gray hairs induced by cosmic radiation.

SPACE VEHICLES

When the designer makes plans for a space vehicle for man, he must constantly keep in mind the closed environment previously described. If man is to survive in space he must be protected against extreme temperatures; be provided with oxygen, food, and water; and not be subjected to high g forces over prolonged periods. He may need to be provided an artificial gravity if he finds that he cannot adjust his life processes to the weightless condition; and he must be shielded from bombardment by meteoric material, cosmic rays, and other harmful radiations. To lift the vehicle and its closed environment into space, to travel unprecedented distances and return safely to the earth, requires a tremendous amount of energy, and for a long time no other method can be utilized except that of storing it within the vehicle.

Finally, since the reentry problem is crucial, a space vehicle must be gently braked before reentry and some kind of device be brought into operation to allow it to land safely. Space vehicles, to survive leaving and reentering the atmosphere at great speeds, must be built to withstand greater stresses than aircraft.

Space scientists like Goddard, Oberth, and Tsiolkovsky, laid the foundation for designing space vehicles many years ago. Much has been learned about the subject since they did their early work, and much more needs to be learned.

Designs in Use or Under Development

Today, United States designers of space vehicles have two well-tested vehicular types from which to work: the X-series research aircraft and the ballistic missile.

Research aircraft have carried men to increasingly higher altitudes. They have explored such factors as turbulence and aerodynamic heating at high altitudes. The X–15, designed to fly as high as 50 miles, was also designed to provide information on flight conditions at these higher altitudes, including reaction to weightlessness, about problems relating to exit from and reentry into the atmosphere, and the effects of increased acceleration and deceleration. Information supplied by the research aircraft, supplemented with data from artificial

satellites, continues to give designers more and more practical knowledge about the environment in which the space ship is to travel (Fig. 134).

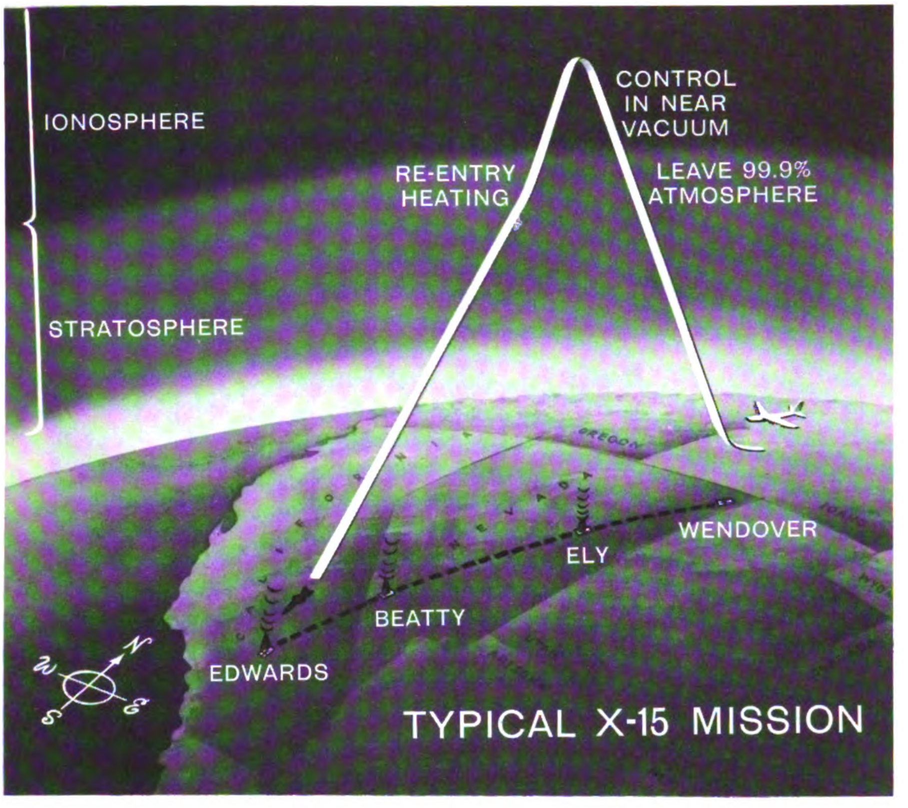


FIGURE 134. The operational area of the X–15 rocket craft.

The ballistic missile, which has a much greater range and speed than the research aircraft, is the vehicle which has been developed into a space vehicle. Early ballistic missiles, when staged to reach velocities necessary for space flight, were little more than hollow shells for holding liquid propellants, with the plumbing and machinery necessary to pump them, and equipped with combustion chamber and nozzle. This was dictated by the fact that the largest fraction of the weight of a chemically fueled space missile must be propellants, and early designs could not allow for much payload weight.

In Project Mercury the problem of keeping the ballistic missile design intact is solved by having the crew space enclosed in a capsule that can be separated from the missile. This is a safety measure as well as a solution to the practical problems of design. If trouble should develop in the missile before the capsule orbits, rockets will automatically fire and lift the capsule from the booster in a trajectory type of flight from which it can be parachute-lowered to earth a safe

distance away from the launching site. In solving the reentry problem of the Mercury capsule a safety margin between heating and g load was reckoned by engineers who utilized the results of many experiments and past experience with heating and g-forces. The Mercury capsule is only a simple experimental design for a space vehicle, but from its journey into orbit lessons have been learned that are helpful in designing future space vehicles (Fig. 135).

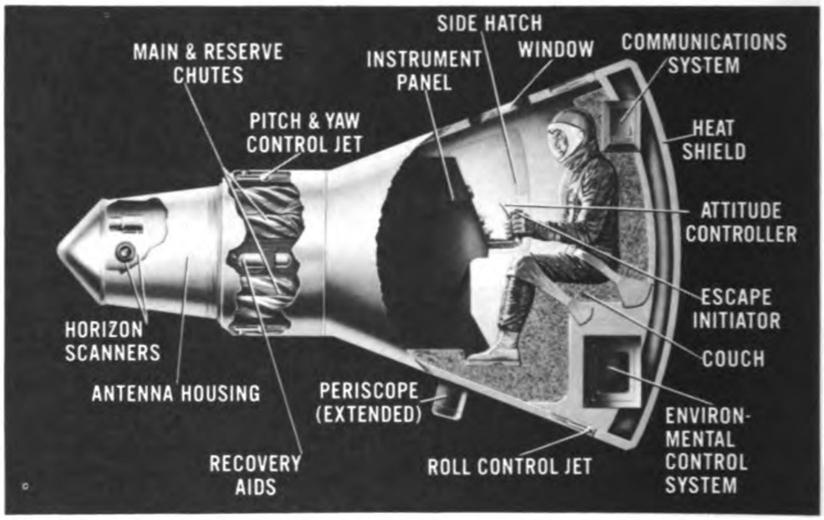


FIGURE 135. A stylized cutaway of the project Mercury capsule.

In addition to altering ballistic missile designs to convert them into space vehicles, the family of large superboosters under development by the National Aeronautics and Space Administration offers possibilities. Of these boosters, the smallest (the Scout) is a research rocket, which will probably be used for unmanned experiments. The larger boosters (Centaur, Saturn, and Nova) have been designed for use in manned travel. Saturn, a staged system, has a cluster of eight engines, which provide a total thrust of 1.5 million pounds. Dr. Wernher von Braun estimates that this system should be able to orbit a manned space laboratory. If a nuclear engine could be developed for the third stage, Saturn might be used for a manned flight as far as Mars.

The two-stage Nova will increase significantly the total thrust available. Nova has six engines, each developing 1.5 million pounds of thrust. The Nova will ultimately have four or five stages.

The Dynasoar, a boost-glide test vehicle, has been designed under an Air Force contract as a follow-on to the X–15 test vehicles. Dynasoar, half ballistic missile and half aircraft, was designed to be rocketed by a Titan intercontinental ballistic missile to an altitude in excess of 100 miles. An important purpose of this is to provide information about pilot-controlled reentry into the atmosphere, and the varying problems of maneuver back to recovery base. Upon reentry, the

vehicle with pilot inside must experience high aerodynamic heating, and structures must undergo terrific stresses. Continuing tests with Dynasoars should provide safer reentry techniques and controls. This vehicle was not originally designed for continued orbiting, but an advanced design Dynasoar could be made to orbit the earth many times at low altitudes to serve as part of a low-orbit offensive system.

Theoretical Designs

In 1922 and again in 1929, Oberth, the pioneer mentioned earlier, proposed a satellite vehicle for stockpiling propellants for interplanetary travel. About 1929 Baron von Pirquet, who was active in the Austrian rocket society, proposed a course for rocket development which would proceed from experimental instrument-carrying rockets, to rockets for carrying mail, and then to piloted rockets that would leave the atmosphere and become space ships. The first space ships would be used to build a space station. A Soviet writer, Capt. H. N. Potocnik, made what amounted to the first preliminary design proposal for a space station. The key part of his design was the Wohnrad, or dwelling wheel. Dr. Wernher von Braun has designed a more advanced vehicle incorporating this idea. His dwelling wheel consists of three tubular spokes and a bulbous hub.

One system of space vehicles is based upon the idea that, after a man has succeeded in making an orbital flight, he should establish a station in orbit for use as a base for more distant travel. Ferry rockets would be used for adding to material in orbit to build a kind of prefabricated space station and to assemble a deep-space vehicle which would then be fueled and provisioned.

A space station used as a launching platform for deep space exploration need not be manned. A space station could be built by staging a rocket with thrust equal to that of the Saturn rocket currently under development. One problem in operating to and from the space station would be that of devising a technique for accurate rendezvous.

Navigation and Control

Space vehicles need some kind of navigation and control system, with power to provide reaction force, since only reaction force will reorient a space vehicle, and accelerate it.

To develop a system of navigation in space, a whole new set of instruments and reference systems will be necessary. In space there is no horizon, and the navigator will have to establish an artificial point of reference. Navigators in space could not reckon position by "shooting the stars" as it is understood in navigation on the earth's surface. In earth navigation, calculations using stars or planets need the earth's horizon as a reference point. Once a vehicle is away from the earth, a navigator will have to reckon his location according to the position of the planets or of artificial satellites. Problems of navigation will be further complicated by the fact that it is necessary to consider the velocity of the vehicle relative to the earth and to the planet that one is approaching. For calculating the position of an unpowered vehicle in space, six independent

measurements are necessary. These measurements must be related to a known reference system, which must be maintained by some form of instrumentation on board. The best known way for setting up such a system is to use the gyro-stabilized platform. If the space vehicle is powered, the trajectory can be altered, and even more measurements will be required. The complicated computations will have to be made by automatic equipment.

Once a vehicle reaches the altitude of about 30 miles above the earth, it can no longer depend upon aerodynamic lift or aerodynamic controls. Reaction controls must be used instead. A solution to the problem was made in designing the X–15. Small jets of hydrogen peroxide located in the nose and wingtips were incorporated to control the attitude of the aircraft. Since a space vehicle does not have the stabilizing influence of air, it can easily be set to tumbling, spinning, or rolling, and all attitude control by air is lost. The reaction principle must surely be used for working out a more complex control system for space ships. To stabilize the experimental meteorological satellite Tiros I, rockets were used to impart spin.

Propulsive Power

The design of a deep-space ship calls for propulsion from nuclear and electric rocket motors now under design development. A rocket motor that operates by using energy from thermonuclear reaction, photon pressure (the same light pressure mentioned earlier which shifts satellites' positions), ion propulsion, or plasma could provide thrust over extended periods. These have previously been defined. Once a vehicle is in space, only a relatively small amount of thrust is necessary to increase orbital speed and carry the vehicle to enormous distances. The development of liquid propellant chemical rockets has been carried about as far as possible. Most propellants now in use have a specific impulse of about 275. Any liquid propellant that might be developed in the future probably would not have a specific impulse of more than 400. The term "specific impulse" is used to describe efficiency in rocketry, in this case of fuel. The first crude laboratory device for an ion rocket yielded a specific impulse of nearly 1,000. The Saturn and Nova, now under development, will probably represent about the largest liquid-propellant rockets. When a breakthrough in propulsion is made, the fuel will be capable of storage in a relatively small volume, and there will be more space for the crew.

Auxiliary Power Systems

At about the same time that there is a breakthrough in developing much more efficient propulsive power for space ships, advanced auxiliary power systems will probably be developed also. The larger and more complex a space ship becomes, the more auxiliary power will be required to support life in it. Auxiliary power systems can be designed so that they do not require additional fuel to be stored in the ship but can draw their energy from the sun.

Solar cells made of specially treated silicon wafers are already being used successfully to power radio transmitters on satellites, as pointed out earlier.

Another possibility for using solar energy is through heating a working fluid. Heat from the sun can be attracted by a large sphere or another container, in which the fluid is stored. The National Aeronautics and Space Administration has under design development a project for a solar plant to generate 3,000 watts of electrical power continuously for at least a year (Sunflower I). Such a plant could be installed in the nose of a Centaur or Saturn. Present plans are to use a petal-type solar collector that would be folded when a satellite is launched but would unfold in space to a diameter of about 32 feet. It would collect the sun's heat and concentrate it on a boiler to vaporize liquid mercury, which could be condensed and used over and over again. The mercury vapor would drive a turbine for generating electricity.

TRAVEL TO THE MOON

The moon is the first major objective in space travel, since it is the natural body closest to the earth. Even now designs are being developed for advanced space ships which will be capable of transporting a man or crew to the moon. Moon probing has progressed by several steps. According to the 10-year program of the National Aeronautics and Space Administration, most of the United States' steps toward exploration of the moon in the 1960's were stated as follows: (1) an impact on the moon, (2) controlled landing of an unmanned vehicle, (3) unmanned circumnavigation, (4) manned circumlunar flight and orbiting, and (5) manned landing. The U.S.S.R. has already made an impact contact with the moon and an unmanned circumlunar probe has photographed the hidden lunar surface, as pointed out before. The first United States Pioneer shots, which were intended to establish an artificial satellite of the moon, failed in the effort but gave scientists practical information on the earth-moon trajectory. The probes have also given a new impetus to study of the moon. An accurate photographic map of the moon's visible face is being compiled by the French astronomical observatory on Pic du Midi de Bigorre, in the Pyrenees, and by the University of Manchester, in England, under the sponsorship of the U.S. Air Force. The projected map will be on a scale of one to a million and will require some 200,000 pictures to make possible precise calculations of distances and of the size of physical features.

Nature and Characteristics of the Moon

The moon is at a mean distance of 240,000 miles from the earth, which, viewed from the perspective of interplanetary distance, is close. At the closest point in its orbit, the moon is 221,463 miles from the earth and at the farthest point, 252,710 miles. In comparison with the earth, the moon is quite small. Its diameter is only 2,160 miles, or a little more than one-fourth that of the earth. Its gravitational pull is $1/6$ that of the earth's, its volume is $1/50$, and its mass is $1/81$. Like the other heavenly bodies, the moon travels in an elliptical orbit. It revolves in its orbit around the earth at the rate of 2,268 mph. Because of the relative motion of the earth and the moon, the moon always keeps the same side turned toward the earth.

The moon is of particular interest to astronomers because it has not undergone erosion as the earth has. Since the moon has practically no atmosphere, the lunar surface has not been changed by the effects of wind and water. About one-half of the visible side of the moon is covered with so-called mare (seas), which are actually vast plains of relatively flat rock covered with some fine debris and dust. The plains are pitted with giant craters and marked by deep clefts thought to be caused by quakes. The plains are believed to be the result of either meteoric bombardment or volcanic action. Surrounding the plains are high mountains. No seas or bodies of water exist.

Past conjecture concerning the depth of the dust layer on the plains expressed the fear that it might be deep enough to bury any vehicle from the earth landing in it. Now, the depth of the dust layer is established at about 1 millimeter, or roughly 0.04 inch. Measurement was made by means of reflected radiation signals received by giant radio telescopes.

Temperature changes on the moon are recorded by sensitive thermocouples, upon which is focused radiant heat from the moon, collected by large telescopes. They show that, at midday, rocks that are exposed to the sun reach temperatures just about that of boiling water on the earth's surface (212° F.). During the long lunar nights (14 earth nights in length), the temperature drops to −250° F.

As viewed from the moon, the appearance of the earth goes through phases similar to those familiar to us when viewing the moon. "Full earth" occurs at the same time the "new moon" is visible from earth. At this time the earth as seen from the moon is some 60 times as bright as full moon seen from the earth.

Moon Probes

Since the earth is much larger than the moon, with greater gravitational force, and since the moon has little or no atmosphere, it will be much easier to leave the moon and travel to the earth than to leave the earth to travel to the moon. Unfortunately, the probes must make this latter effort, and also the moon is a difficult target to hit from the earth. The relative motion of the earth and the moon must be considered. The moon is moving around the earth at a speed of about 2,250 mph at the same time that the earth is revolving in its orbit around the sun at a speed of about 66,000 mph, and the bodies are moving in somewhat different planes. Even a relatively small error in computing the velocity of the rocket will cause the probe to miss.

To reach the moon, a rocket has to attain a velocity of 99 percent of that for escape from the earth (roughly 6.8 miles per second at the surface of the earth). At an altitude of 350 miles, the velocity of the rocket has to be about 34,800 feet per second. At this point fuel burning may cease, but the rocket will continue to climb, although with fall off of velocity because of the gravitational pull of the earth. Gradually, as the rocket vehicle recedes from the earth, the gravitational pull becomes less. Velocity decreases until the rocket is about 23,600 miles from the moon, or roughly nine-tenths of the way. At approximately this point the gravitational pull of the earth and of the moon balance each other and, as

a result, no gravitational pull hinders or aids the rocket vehicle. As the rocket continues, it comes under the gravitational influence of the moon and begins to fall toward it, its velocity increasing as it falls (Fig. 136).

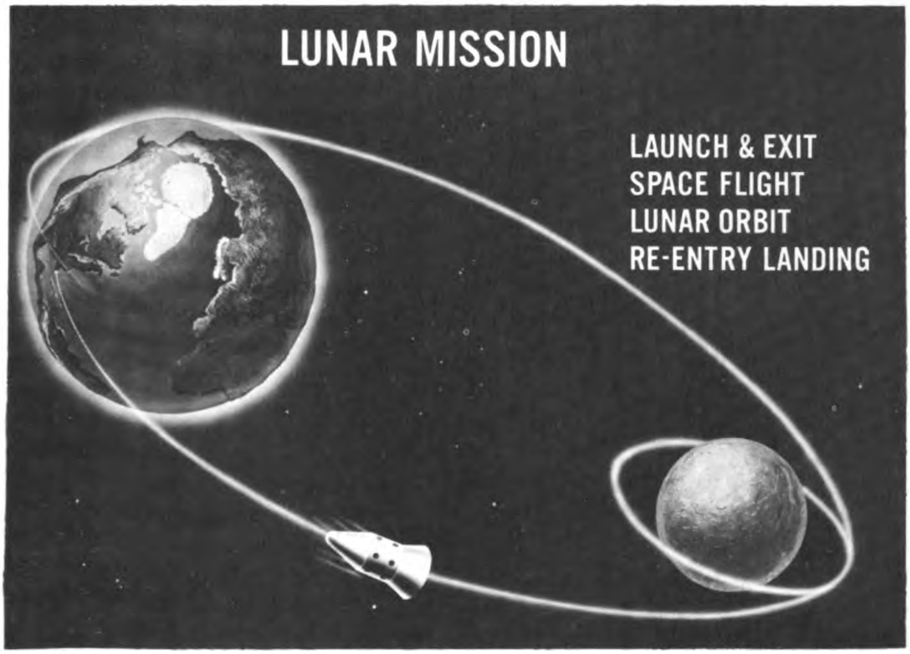


FIGURE 136. Major phases of a lunar mission.

The time required for completing a free-fall trajectory to the moon depends, of course, upon the initial velocity of the rocket vehicle, i.e., the velocity at fuel cutoff time near the earth's surface. At the lowest initial velocity possible, the flight time would be about 5.5 days. With initial velocity increased only 1 percent, flight time would be cut down more than half, or to 2 days.

A probe may be sent from the earth to circumnavigate the moon and return to the earth without a further powered phase if the initial velocity is kept lower than the local escape velocity. The vehicle must be launched so that it will intersect the moon's orbit at a point ahead of the moon. Then it can be swung around by the moon's pull and thus be pointed back toward the earth. This is the low-velocity, or the "figure-eight," orbit often referred to in popular literature. Total time for a round-trip free flight to the moon can vary from about 6 days to as much as a month, the exact time depending upon the initial velocity of the rocket.

Manned Moon Voyages

The X–15 tests, Project Mercury, and later moon probes have been and are preliminary United States steps toward determining the feasibility, practicability,

and possibility of manned voyages to the moon. For such a trip, intermediate initial velocities would have to be used. On trips made in the shortest possible time, accelerations would be too high. If the longest possible time were allowed, the accelerations could be kept lower, but the chances of aiming error would be too large. For a safe return to the earth from the moon, an extremely accurate approach guidance system is needed.

The question of whether a base on the moon would have real military value is a controversial one. It is true that an observatory on the moon would be of immense benefit to science. As a first-stop space station, however, the moon is not promising. The tremendous velocities required to reach the moon approach within about 99 percent those needed to voyage into interplanetary space. A space station much closer to the earth would be more useful, especially in the early stages of astronautics.

There is little doubt that if man has the ingenuity to reach the moon, he could find the means to establish a base there. Although the bleak dust plains with their hazardous clefts and the hostile environment present a formidable prospect, man might be able to exploit the environment to some extent. He might, for example, be able to process water and oxygen from hydrides known to be present on the lunar surface, but even then he would still have to maintain a closed environment. His survival might depend upon keeping himself from being exposed to the airless surface conditions and upon protecting himself from bombardment by meteors, cosmic rays, and other radiation.

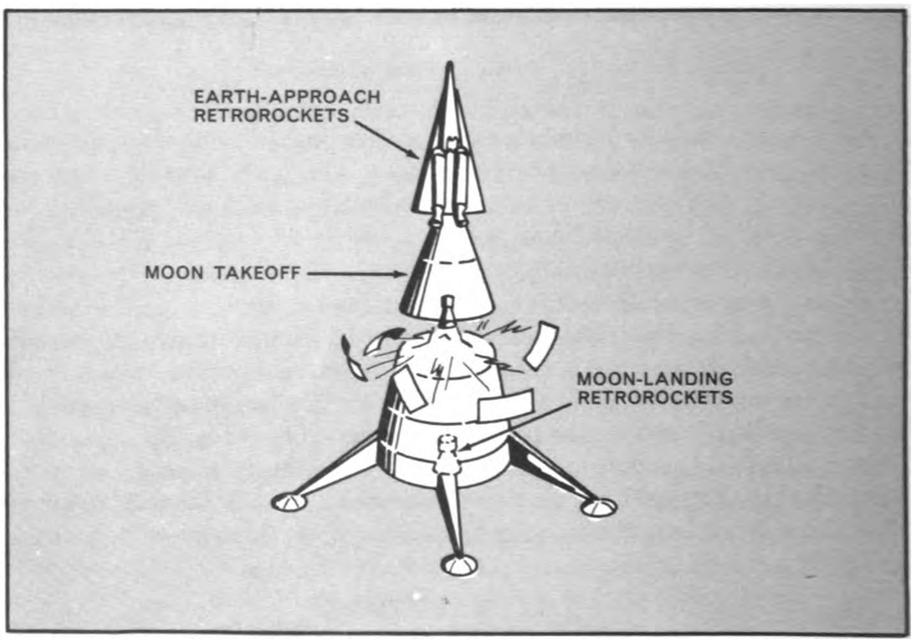


FIGURE 137. Soft-landing vehicle, full assembly.

Questions as to the wisdom of a manned trip to the moon might be ignored for the moment and a lunar landing considered purely for what it teaches concerning the mechanics of space flight. As a rocket or other body approaches the moon at the end of an earth-moon trajectory, it is traveling at a tremendous velocity. Since the moon has little or no atmosphere, there is nothing to act as a brake. With no other decelerating device, the body would collide with the moon's surface—a "hard" landing. A "soft" landing might be accomplished by firing, at a precalculated distance from the moon, a retrorocket—a rocket fired in the direction opposite to that in which the body is traveling, so acting as a brake. (Fig. 137.) Such a safe landing would result if the amount of braking is adequate.

INTERPLANETARY TRAVEL

The same principles apply to interplanetary travel as to flight to the moon except that, in the case of interplanetary travel, somewhat higher escape velocities are needed and the sun's gravitational force, rather than the earth's, plays the dominant role. When a body escapes from the earth into interplanetary space, it takes up an independent orbit around the sun. It then exists as a kind of artificial asteroid unless it is "captured" by a planet's gravitational field into which it has traveled and becomes an artificial satellite of that planet.

As in the case of travel to the moon, free-flight trajectories can be computed to each of the planets. If a vehicle is to go to a planet whose orbit lies beyond that of the earth (Mars, Jupiter, Saturn, Uranus, Neptune, or Pluto), it is launched in the direction that the earth travels along its orbit. This adds the velocity of the earth in orbit (about 100,000 feet per second) as a bonus to the velocity of the rocket, and the space vehicle would take up an orbit outside that of the earth. If the vehicle is to go to a planet between the earth and the sun (Mercury or Venus), it is launched in a direction opposite to the earth's revolution in order to reduce its velocity below that of the earth. Actually it would take almost as much energy to produce the reduced velocity of a vehicle to travel to Mercury as it would to produce the accelerated velocity needed for a trip to Jupiter. Higher initial velocities would reduce the transit time, which for the inner planets is expressed in terms of days and for the outer planets, in terms of years.

Because interplanetary distances vary greatly, depending upon the relative positions of the planets in their orbits, it will be necessary to schedule flights when the planets are at the most favorable distance from the earth.

The method or combination of methods a vehicle would use for making a landing on a planet would depend upon the amount of atmosphere present. If there is little or no atmosphere, as in the case of the moon, a retrorocket must supply the braking force. If there is some atmosphere, propulsive power might be saved by using frictional braking and winged surfaces.

As to questions asked about the feasibility of travel to the planets, one must wait upon results achieved in explorations of the moon. In the meantime, the 10-year program of the National Aeronautics and Space Administration in-

cludes plans for probes to be made of Venus and Mars, and instruments will be landed on either Mars or Venus. Manned flight to the planets might have to wait for a development of nuclear and electrical propulsion systems, space navigation systems, and establishment of way stations in space.

With the exception of the moon, Mars presents the most likely possibility for establishing a base outside the earth. Venus, with its heavy cloud cover, is now an almost unknown quantity, as pointed out earlier. As man advances into space and establishes observatories where he can study the solar system and view the planets without the interference of the atmosphere, he will make new findings that will help to advance interplanetary travel.

For traveling to the outer planets, propulsive power capable of producing enormous velocities is needed to keep flight time within reasonable limits.

ASTRONAUTICS IN OTHER COUNTRIES

So far, the chief aim of this account of astronautics has been to outline United States accomplishments and plans. Additional mention has been made of German and Soviet work only. Interest in astronautics is, of course, not confined to these nations. Every large nation includes some kind of private or governmental organization whose main interest is astronautics or rocketry. At the present time, only the United States and the Soviet Union produce ICBM's, which make space probes and experiments with artificial satellites possible. It is rumored that Red China is cooperating actively with the U.S.S.R. in conducting astronautical experiments, but the equipment used belongs to the U.S.S.R. Great Britain, Canada, and Australia have similarly cooperated with the United States.

Soviet Achievements and Interest

The first artificial satellite launched by the U.S.S.R. in October 1957 announced to the world the existence of a rocket research and development program that had long been shrouded in military secrecy. Scientists who had closely followed the progress of Soviet work in astronautics, however, were not surprised. They knew that the U.S.S.R. had had an organized space-rocket program for some time, although they were not able to learn details about Soviet rockets. Only when the satellites were launched could scientists learn more. They were able to track them, compute the place of launching, and the amount of thrust required of the rockets that sent them into orbit. Speculations could also be made about the type of propellants used.

The launchings of the early Soviet satellites were traced to the Kyzyl Kim Desert, about 250 miles southeast of the Aral Sea. The launchings were made possible by rocket engines with a thrust as high as 265,000 pounds. The Soviets were motivated to develop these large rockets to carry large nuclear warheads. Instead of trying to develop small nuclear warheads and miniaturized controls and telemetering devices, they froze their designs early and then set about to produce the large rocket engines that would carry them. These large rockets have paid off handsomely in space research. Because of the tremendous energy re-

quired to generate the velocities needed in astronautics, progress depends upon developing increasingly greater amounts of thrust. Calculations are that, with present rocket thrust, the U.S.S.R. could make a manned flight to the moon. The impact of a vehicle upon the moon and the circumlunar flight, as well as long range terrestrial tests and demonstrations of accurate placement of ICBM payloads, show that the Soviets have developed their missile guidance and control systems to a considerable degree of reliability. Since the U.S.S.R. has already made significant moon probes, has launched a 4.5-ton space vehicle in orbit around the earth, and has recovered two living dogs from orbit, expectations are that this nation will soon make further significant progress.

Soviet scientists and engineers have done a vast amount of original work. Men like Semenov, a recent Nobel Prize winner for chemistry, and Sedov, distinguished physicist and aerodynamicist, attest to Soviet ability in the technical fields, and other Soviet scientists have won the respect of their colleagues. No matter how their scientific accomplishments have been used for political ends, their work itself is sound. In dealing with its astronautical scientists the Soviet government has not used its usual heavy-handed methods. These scientists and engineers are given certain responsibilities and ample means for meeting them, and then they are generally left to themselves to work out their problems as they see best.

The Soviet people have a rich background in astronautics. They speak with awe of Tsiolkovsky, the Father of Astronautics, who began his extensive work before the end of the 19th century. The Soviet followers of Tsiolkovsky authored many original papers on rocket development until the shroud of secrecy descended on rocket research in 1935. While the early Soviet hierarchy hid the work of Soviet space scientists from the world, they themselves endorsed it. Stalin was an admirer of Tsiolkovsky, whose memory was honored in 1954, when the Presidium of the U.S.S.R. Academy of Sciences established the Tsiolkovsky Gold Medal, which is awarded every 3 years.

By 1934, the U.S.S.R. began a systematic rocket investigation program. This was only 5 years after Germany initiated its rocket program but 8 years before a systematic military research program was started in the United States. Today the Soviet Union is studded with rocket factories and experimental facilities, and the nation is organized to carry on an enormous program of rocket production and astronautical research.

The military services are well represented on the Interdepartmental Commission on Interplanetary Communication of the U.S.S.R. Academy of Sciences, whose membership list includes some of the world's top scientists. The Commission was set up to develop both theory and the practical work necessary to advance the study of cosmic space and space flight. The Commission has been accepted for membership in the International Astronautical Federation. In 1955 the Soviet Government announced that a Commission on Astronautics had been set up with Sedov as chairman. Another group influential in advancing astronautics in the Soviet Union is the Astronautics Section of the Chakalov Central Aeroclub of the U.S.S.R.

The Soviet Union was first represented at international conferences on astronautics in 1955 when Sedov and an astronomy professor from Leningrad State University attended the Sixth International Astronautical Congress sponsored by the International Astronautics Federation. It was at this meeting that Sedov announced a forthcoming Soviet artificial satellite. From that time on Soviet scientists have been allowed to attend meetings and symposiums, and they have traveled around the world.

If the early Soviet astronautical scientists were handicapped by their reticence, they did learn to benefit from the contributions of others. Soviet space scientists have always kept up with the literature produced in other countries, and they have made systematic abstracts. In this way they have not wasted time in reproducing experiments when the results were well established.

At the same time that Soviet scientists began to discuss artificial satellites, they also talked of manned flight to the moon, and it is known that they have a special interest in the problem. All possibilities for free-flight earth-moon trajectories have been explored and computed in the Soviet Union, just as they have been in the United States. Soviet scientists write of an exploratory trip to the moon to be made by an unmanned tankette, which would roam the surface and collect data.

Soviet scientists have had considerable success with recovering test equipment and living animals from extremely high altitudes and they have carefully worked out the techniques for recovery of space capsules. From reports coming from the Soviet Union, it appears that their space experts have already looked beyond manned trips to the moon, to travel to the planets, and even to the cosmos beyond the solar system.

International Cooperation

The U.S.S.R. has so far rejected overtures made by the United States to cooperate in tracking satellites, but the Soviets aver that they approve of the principles of cooperation. They point out, however, that they would prefer to work through the space conferences of the United Nations. The U.S.S.R. and the United States have made a tentative agreement to form a permanent United Nations committee to regulate the peaceful uses of outer space. In the meantime, the International Council of Scientific Unions, in October 1958, set up the Committee on Space Research (COSPAR) to continue the international cooperation begun during the International Geophysical Year (Fig. 138).

The U.S. National Aeronautics and Space Administration is developing a program of international cooperation by which the United States will launch the satellites of other nations. An understanding has already been reached to launch the first of three British satellites and a Canadian satellite. Now that England has given up research on the Blue Streak long-range ballistic missile, it has no program underway for developing boosters for space research. Agreements have also been made with the Australian Government to continue the work done at the Woomera tracking range during the International Geophysical Year.

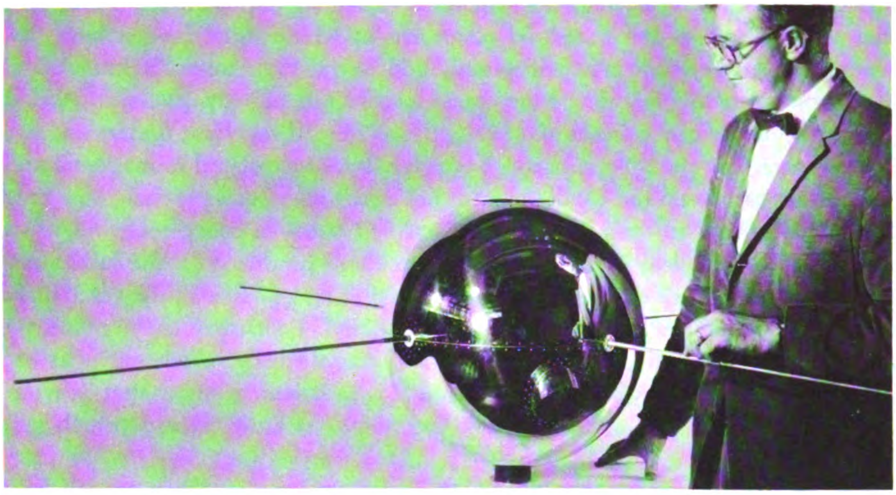


FIGURE 138. The 20-inch cloud cover satellite, a part of the U.S. program for the International Geophysical Year.

An 85-foot steerable tracking dish is under construction at Woomera. A second antenna is scheduled for southern Africa. These will add to capacity for tracking deep space probes, which is now done mainly by the large radio telescope at Jodrell Bank, England. Larger radio telescopes are under construction at Sugar Grove, W. Va., and at the radio astronomical station of the Lebedev Physics Institute of the U.S.S.R. Academy of Sciences, which is near Moscow. When these telescopes are completed, they will present a worldwide chain of receivers for space communications, if some system of cooperation can be worked out.

FUTURE OF ASTRONAUTICS

From the brief sketch of developments in astronautics in other countries, as well as in the United States, it is clear that space exploration will ultimately affect all man's thinking. Not only will knowledge of the distant heavens be added to, but more local and near at hand phenomena will be better understood. For example, new subatomic particles may be found in studies of cosmic rays. Space research has already opened the door to a revolutionary era in electronics and communications, and space scientists have developed positive knowledge about the exact shape of the earth and the presence of the Van Allen radiation belts around the earth. Other discoveries of immediate value will no doubt be uncovered as the vast amount of data transmitted from the artificial satellites is studied and evaluated.

When man is able to establish observatories in orbit, as scientists think will be possible in the not too distant future, he can look back at the earth and discover knowledge about his planet that could not be learned before, he can gather data about the space medium in which he is traveling, and he can look at the universe through his telescopes, unhampered by an intervening layer of air, and make

findings that now lie beyond the reaches of the imagination. Scientists believe that we are now at the threshold of an era in which some far-reaching discoveries are to be made that will greatly add to our basic scientific knowledge. Many pieces of a gigantic cosmological puzzle are already in hand. Added data will provide other pieces and presently, as they fit together, understandings will increase. For example, sunspots and solar flares are related to magnetic and radio disturbances on the earth, but it is not now understood precisely how they are related. Also, information about electrified gases in space leads scientists to believe that nuclear explosions similar to those produced in the laboratory take place in space. Geoscientists who are now getting a picture of the earth from outside its cloud cover are gaining a new perspective. Because of the urgent need for refining computations to arrive at more accurate trajectories, scientists are no longer willing to say with Newton that it is sufficient to know that gravitation exists. They want to learn something about its basic nature, which still remains a mystery.

For the Air Force, space exploration obviously means a greatly extended field of operations. It is true that the Air Force has already been flying at space-equivalent conditions for man for many years, but flight is now entering the suborbital regions where space-equivalent conditions exist for aerodynamic lift and controls. Space vehicles will soon be flying at orbital heights, where the rocket engine will operate at its greatest efficiency. Later there should be breakthroughs in the development of nuclear and electrical rocket engines, which will make it possible to traverse vast distances at enormous velocities.

Artificial satellites will make possible more reliable communications, improved early warnings of hostile missile launchings, and better reconnaissance. All these improvements will affect the operation of Air Force weapon systems. Any knowledge obtained about space and the upper atmosphere will aid in the development of ICBM's, which are in reality space vehicles because their trajectories extend into space.

Concerning the possibility of using artificial satellites for bombing attack, it is sufficient at this point to mention that this, and possible countermeasures, are even now under scrutiny by both the United States and the Soviet Union.

At some time in the future the United States will probably establish a base on the moon, but it is too soon to decide whether the need for such a base would be great enough to offset the vast amount of resources that would be required. Its potential military value is likewise under study.

Concerning the possibilities of interplanetary flight, one can only repeat the words of Tsiolkovsky, written in 1913: "Mankind will not stay on the Earth forever, but, in the pursuit of the world and space, will at first timidly penetrate beyond the limits of the atmosphere and then will conquer all the space around the sun." Later Tsiolkovsky said that a century would elapse before the events that he was predicting would come to pass. Many of the predictions of the early space scientists have already come to pass with amazing accuracy. As to what interplanetary travel would mean ultimately in terms of human freedoms, or release from the scourge of war, only philosophers may conjecture.

APPENDIX A

Principal USAF Operational Aircraft

Aircraft of the U.S. Air Force are identified by a simple system of numerals and both prefix and suffix letters. The numerals are used to identify the basic model, the prefix letters individually or in combination to indicate the functional category, and the suffix letter to indicate a major modification of the basic model. Listed below are the prefix letter meanings.

A	Amphibian	M	Missile
B	Bomber	Q	Target Drone
C	Cargo (Transport)	R	Reconnaissance
D	Drone Director	S	Search and Rescue
E	Special Category	T	Trainer
F	Fighter	U	Utility
G	Missile Carrier	V	Convertiplane or Personnel Transport
H	Helicopter	W	Weather Reconnaissance
K	Tanker	X	Special Research
L	Liaison		

The designation RB–47E, for example, indicates that the basic Boeing medium jet bomber has been converted with special equipment to perform as a reconnaissance aircraft; the suffix E tells us that this is the fifth major modification of the basic model. A reference to a WB–66D indicates that this, the fourth major modification of the Douglas B–66 light bomber, has been converted for use in weather reconnaissance.

The descriptions of the following basic operational aircraft are arranged alphabetically by functional type designation, and numerically within those categories. Some older models, not listed here, are still found in special assignments, although the basic aircraft has become obsolescent as an operational aircraft. For security reasons, only unclassified information is presented here. In actual use, speeds and operational altitude may exceed those indicated, and modification with specialized classified equipment may increase capabilities far beyond the descriptions which can be made public. The civilian manufacturer is mentioned last.

New categories will appear, such as ducted-fan-lift vehicles and air-cushioned surface skimmers. These and others are now in experimental stage.

B–26 Invader. This World War II and Korean War tactical bomber, powered by two piston engines, is still in use as a tow-target carrier and for such experiments as those investigating air-launched drones and missiles. Also, some have been converted for use as administrative craft for the Air National Guard. Douglas.

B–29 SUPERFORTRESS. This four-engined, piston-driven World War II heavy bomber was converted for use as an aerial tanker in 1948. Today its main use is as a WB–29 hurricane hunter with the Air Weather Service. Boeing.

B–47 STRATOJET. Through the 1950's the Stratojet was the major component type in the SAC inventory. It is now programed for replacement by the B–58 Hustler. Equipped with six jets (J–47), it is 107 feet long, with wingspan of 116 feet, height of 28 feet, and speed of over 600 mph. It has an unrefueled range beyond 3,000 miles, ceiling above 40,000 feet, bomb load capacity over 20,000 pounds, and a normal crew of three. Additional takeoff thrust is provided by 33 RATO units of 1,000 pounds each. Extremely versatile, the basic model has been modified for both RB and DB use, and at one time even as a KB. It is refueled with a flying boom system. Boeing.

B–50 SUPERFORTRESS. Originally produced as major modification of the B–29, the Superfortress has been converted to a KB–50. The KB–50J added two jet engines to the original four piston engines and was adopted as a regular aerial tanker for the Tactical Air Command's Composite Air Strike Forces. Span 141′2″, length 99′, height 32′7″, speed over 400 mph, ceiling 35,000′, range beyond 2,000 mi. Boeing.

B–52 STRATOFORTRESS. SAC's heavy bomber is powered by eight J–57 turbojets (the B–52H uses turbofans). The span is 185′, length 156′, height 48′ (G and H models are 1′ longer, only 40′8″ high), speed over 600 mph, ceiling above 50,000′, range over 6,000 mi (G model, over 7,500, and H model over 9,000). Normally it has a crew of 6. Modifications permit use in launching guided and ballistic missiles as well as bombs. Boeing.

B–57 NIGHT INTRUDER. This is the USAF-adapted version of the British Canberra. It is no longer used as a bomber, but modified versions do reconnaissance and tow-target work in air-to-air and ground-to-air exercise at high altitudes. As a bomber it featured a pre-bomb-loaded 180 deg.-revolving bomb-bay door which in dropping position offered no wind-resisting protuberance to reduce speed. The B–57C had dual controls to serve as a trainer. The B–57E was convertible to and from bomber or tow-target use quickly and relatively simply by removal of tow-target fittings. Span 64′, length 65½′, height 14.8′, speed over 600 mph, ceiling over 45,000′ (over 55,000′ in RB models), range over 2,000 mi. It was redesigned and produced in United States by Martin.

B–58 HUSTLER. Produced for SAC, this was the world's first supersonic bomber. Weapons and fuel are carried in disposable pods. The B–58 has unusually long landing gear to give clearance for pods on takeoff. Each main strut has eight wheels. Delta-winged, with four J–79 turbo-jets and afterburners, the B–58 is fully ECM-equipped. Pilot, bombardier navigator, and ECM operator make up crew. Span 65′10″, length 96′9″, height 31′5″, speed over mach 2 (1,324 mph at 35,000′), ceiling above 60,000′, range intercontinental with refueling. Convair.

B–66 DESTROYER. This versatile twin-jet light bomber is modifiable for many roles in TAC's Composite Air Strike Forces. It introduced many automatic electrical control system innovations, eliminating a number of pilot actions in-

volving manual switches. It has been used mostly in RB and WB operations. Span 72′6″, length 75′2″, height 23′7″, speed over 700 mph, ceiling above 45,000′, range beyond 1,500 mi. without refueling. Normal crews: B–66 and RB–66B, 3; RB–66C, 4; WB–66D, 5. Douglas.

B–70 VALKYRIE. This radical new superplane, far superior to any existing aircraft, is programed as a mach 3 intercontinental bomber. Its weight and general size are comparable to the B–52G, permitting it to use existing heavy bomber bases. Span 115′, length 170′, speed over 2,000 mph, ceiling about 70,000′. Crew: 4. North American.

C–47 SKYTRAIN. The famed "Gooney Bird" of World War II and the Korean War, this venerable and familiar twin-engined old workhorse was first flown in 1932 as the DC–3. Over 10,000 were built, and many are still in use in almost every country in the world. All USAF commands have used them for freight, passengers, weather, etc., and it has even dropped bombs. A safe, simple aircraft, its slowness (230 mph limit) has forced its phase-out, although many will be traveling the skies for years to come. Span 95′, length 64′4″, height 16′10″, ceiling 24,000′, range 2,125 mi., crew of 3. Douglas.

C–54 SKYMASTER. A four piston-engined cargo-troop carrier, the Skymaster has been used by all major USAF commands as administrative command aircraft as well as functional aircraft, although considered a heavy transport in World War II. It has been replaced in the USAF inventory by aircraft with greater range, ceiling, capacity, and speed. Span, 117′6″, length 93′9″, height 27′6″, speed 300 mph, ceiling 30,000′, range 2,000 mi., 50 passengers, crew of 3 to 5. Douglas.

C–74 GLOBEMASTER I. This cargo transport was once the largest land transport aircraft in the world and widely used by MATS and other commands. Relatively few are left in service; its successor is the C–124 Globemaster II. Four piston engines, span 173′, length 124′, height 43′9″, speed 300 mph, ceiling 30,000′, capacity 50,000 lbs. or 125 troops, crew of 5. Douglas.

C–97 STRATOFREIGHTER. Military counterpart of the civilian Stratocruiser, this four piston-engined heavy duty aircraft has been modified for many different tasks. As a troop transport it can accommodate 134 fully-equipped troops; as an ambulance, 83 stretcher patients with medical supplies and attendants; and as a freighter, up to 64,000 pounds of cargo. Two of a number of special modifications of the C–97 have produced craft with unusual significance. Three models of the first, the VC–97D, are used by SAC as mobile command posts with living quarters for key personnel. A second, variations of which are the KC–97E, –F, and –G, was fitted to serve as an aerial refueling tanker. Until the advent of the jet-powered KC–135, the KC–97 was the standard SAC aerial tanker. Specifications differ somewhat in various modifications, but the latest are: span 141′3″, length 110′4″, height 38′3″, speed 375 mph, ceiling over 35,000′, range beyond 4,000 mi., and a crew of 5. Boeing.

C–118 LIFTMASTER. Military version of the civil airlines DC–6A, this four piston-engined craft is used primarily for low-cost MATS freighting over long distances. Span 117′6″, length 105′7″, height 28′8″, speed 372 mph, ceiling

over 25,000′, range about 5,000 mi., crew of 5. Capacity: 29,500 pounds or 76 fully equipped troops. Douglas.

C–119 FLYING BOXCAR. A familiar sight because of its unusual twin-boom tail assembly, this twin piston-engined cargo craft has been used for many purposes, chiefly troop carrier, paratroop drops, cargo carrying and aerial cargo-drops. Extremely versatile, its chief drawback is its limited range (2,000 miles). Span 109′4″, length 86′6″, height 26′2″, speed 250 mph, ceiling 30,000′, crew of 3–5. Capacity: 30,000 lbs. or 62 equipped troops. Fairchild.

C–121 SUPER CONSTELLATION. This four piston-engined aircraft is famed for its unique fuselage configuration which serves as an airfoil in the same manner as the wing surfaces. The pressurized cabin maintains an 8,000-foot atmosphere up to 22,800 feet. The many modifications of this versatile aircraft include EC, RC, and VC. With extra fuel tanks and six tons of electronic gear, the RC version has been used as a radar-early warning picket ship. The most famous VC model was the VC–121E "Columbine," reserved for the use of President Eisenhower. The C–121 uses both turbo-compound and turboprop engines. General specifications (subject to modifications in various models): span 123′, length 116′, height 23′, speed 370 mph, range over 5,000 mi., ceiling above 25,000′, crew 3 to 5, capacity 40,000 lbs. or 106 passengers. Lockheed.

C–123 PROVIDER. A twin-engined piston-driven assault transport, the Provider (sometimes also referred to as Avitruc) is used primarily by Tactical Air Command and overseas commands. It is designed to operate from short, unimproved landing strips for support operations, and has been modified in a number of ways to meet different mission requirements, including the fitting of wheel-ski landing gear for Arctic operations, and even with experimental jet augmentation using J–44 turbojet engines. Span 119′, length 75′8″, height 34′1″, speed 240, range 3,000 mi., crew of 2 to 4, capacity 24,000 lbs. or 60 fully-equipped troops. It may carry 50 stretcher patients plus medical attendants for evacuation use. In support of ground troops, rear door and ramp permit a 155 mm. howitzer and one truck, or comparable combination of ground equipment. Chase and Fairchild.

C–124 GLOBEMASTER II. This versatile heavy cargo aircraft, powered by four piston engines, is used in all parts of the world by MATS, AFLC, and SAC. Almost all types of military ground vehicles can be accommodated, fully assembled, within its huge cargo space. It has a clamshall nose door with driving ramp, plus mid-section elevator floor and two overhead traveling cranes capable of lifting 16,000 pounds, for quick loading and unloading. The cargo section can be converted to a double deck for troop transport. Span 174′2″, length 130′5″, height 48′3″, speed over 300 mph, ceiling above 30,000′, range 2,300 mi. Capacity: 74,000 lbs., 200 fully equipped troops, or 127 stretcher patients plus 52 sitting patients and medical attendants. Crew of 5 plus doctors and nurses. Douglas.

C–130 HERCULES. Four turboprop engines power this readily convertible assault transport. It is designed specifically for use by TAC for long range, high-speed operations under all conditions, including takeoffs and landings on unim-

proved, short runways. It has been modified for use in ski operations, weather reconnaissance, high-altitude mapping, aerial in-flight refueling, search and rescue, paratroop drops, etc. It features pressurized crew and cargo areas, light armor for crew compartment, power-assisted controls, hydraulically operated loading equipment, rear and side cargo doors, with loading ramp in rear. Standard loads include 92 troops, 74 stretcher cases, 155 mm. howitzer with high speed tractor, nine Nike missiles and boosters, or F–6 refueling trailer (13½ tons). Span 132′6″, length 97′7″, height 38′4″, speed 370 mph, ceiling above 30,000′, range 2,800 mi., max. cap. almost 20 tons. Crew: 4 or 5. Lockheed.

C–131 SAMARITAN. This military transport version of the Convair-Liner 240 is used chiefly for litter-patient transfer or troop carrier. Several have been modified for use as VC-, TC-, and RC-types. Adaptable to severe modification, one model has been completely refitted as the T–29 Flying Classroom, which has in turn gone through a number of further modifications, including VT. Specifications include two piston-driven engines, pressurized cabin, span 91′8″, length 74′8″, height 27′4″, speed over 300 mph, ceiling above 25,000′, range 1,500 mi. Capacity 40 passengers, or 27 litters, or about 12,000 lbs. Crew: 2. Convair.

C–133 GLOBEMASTER III. Also known as the Cargomaster. Although not much larger than the C–124, this four turboprop-engined craft can carry more than twice the payload. It has both fore and aft loading entrances. Primarily designed for hauling freight, it can be modified for many other uses. It can accommodate two prime movers, each weighing 20 tons. Other cargo units could be 16 loaded jeeps, 20 jet engines, etc. It can be fitted with seats to accommodate 200 equipped troops, or can be converted for carrying litter patients as a flying ambulance. Span 179′8″, length 158′, height 48′, speed over 350 mph, ceiling above 25,000′, range over 4,000 mi., capacity 100,000 lbs. Crew: 4 or 5. Douglas.

C–140 JETSTAR. Incorporating the latest sweptback wing design with engines mounted externally to the rear of the fuselage, this four-jet powered executive transport/utility plane produced for AACS (MATS) has a pressurized cabin to maintain 8,000′ atmosphere at 45,000 feet. It is equipped with special electronic gear for worldwide navigational and communication checks and can carry 10 passengers. Span 53½′, length 60½′, height 21′, speed 600 mph, ceiling over 45,000′, range over 3,000 mi., crew: 2. Lockheed.

F–84F THUNDERSTREAK. This tactical fighter is now used only by Air National Guard and NATO forces. J–65 single jet propelled, it can carry 2 tons of either high explosive or nuclear bombs and six .50 cal. machine guns and 24 5-inch rockets. Span 33′6″, length 43′4″, height 14′4″, speed over 650 mph, ceiling above 45,000′, range beyond 2,000 mi. Although the F designation would normally indicate that this is an advanced version of the earlier F–84 models, this is actually a new aircraft (originally called the YF–96A), completely redesigned with different wings and fuselage than the F–84A–G models. The RF–84F Thunderflash is a reconnaissance version of the

Thunderstreak, with virtually the same characteristics, but with air intake ducts located in the wings instead of the nose, and with appropriate reconnaissance equipment. F-84G Thunderjet tactical fighter was the first fighter designed specifically for in-flight refueling and to deliver nuclear bombs. It saw extensive combat operation in Korea; now is primarily used in NATO and SEATO forces. A YF-84J model, called the Super Thunderstreak, was also produced with redesigned features which increased its speed to 700 mph and increased the bomb load to 3 tons. It is now used by NATO forces. All F-84s are produced by Republic.

F-86 SABREJET. This is a tactical fighter-interceptor and the first sweptwing fighter in the USAF. The F-86F gained worldwide fame through its 14-1 kill ratio over Communist jets in Korea and is now used primarily by Air National Guard, NATO, and SEATO. It has gone through many modifications, some of which look like entirely different aircraft. The latest model (L) has data link equipment connected with the SAGE system and is used by Air Defense Command in further developments of that system. Span 37′, length from 38 to 40′, height 15′, speed over 670 mph, ceiling over 50,000′ on latest models, range over 1,000 mi. Armament is varied: six .50 cal. mg, 24 Mighty Mouse rockets, four 20 mm. cannon, etc. North American.

F-89 SCORPION. An all-weather interceptor, the Scorpion is used by Air National Guard. It is powered by twin J-35-A-35 jet engines. It has been phased through a number of progressive developments with changes in fire equipment, and can carry combinations of the following: six 20 mm. cannon, 104 2.75-inch folding wing rockets, six GAR-1 Falcon guided missiles, MB-1 Genie air-to-air missiles with nuclear warhead. Its automatic attack system includes electronic sighting radar and fire control computer. Armament can be fired singly or in salvo, and can be triggered automatically. Span 56′2″, length 53′4″, height 17′7″, speed over 600 mph, ceiling above 45,000′, range beyond 1,000 mi. Crew: 2. Northrop.

F-100 SUPER SABRE. This versatile tactical fighter was the first military operational aircraft to exceed the speed of sound in level flight. The F-100F model is a two-seat version which can be used as a fighter-bomber, a tactical fighter, or as a trainer. All models have a J-57 turbojet engine; the D model has automatic pilot. Can be air-refueled, including refueling from other F-100s. With launching carriage, it can be zero-launched fully armed and fueled. Span 38′, length 47′, height 16′, speed over 800 mph, ceiling above 50,000′, range beyond 1,000 mi. Armament: varied combinations of four M-39 20 mm. cannon, Sidewinder (GAR-8) air-to-air missiles with six underwing pylons for 3 tons of Napalm or HE bombs, and a nuclear bomb capability. North American.

F-101 VOODOO. A twin jet (J-57) all-weather fighter interceptor and reconnaissance aircraft, the Voodoo was originally developed as a long range escort fighter for SAC B-36 bombers. It has been successfully modified for a number of uses. The F-101B is a two-seater version, the F-101C an armored all-weather tactical fighter, and the RF-101 an amazingly versatile reconnais-

sance weapon which in November 1957 set three transcontinental speed records. Until the advent of the F–104, the F–101 was the world's fastest operational aircraft, with an official speed record of 1,207.6 mph, as well as a number of high-speed, long-range operations involving intercontinental deployment. These aircraft are used by TAC, ADC, USAFE, and PACAF. Span 39′8″, length 67½′–69′, height 18′, speed over 1,200 mph, ceiling above 50,000′, range beyond 1,000 mi. without refueling. Armament: varied combinations of four M–39 20 mm. cannon, M–1 Genie, Falcon, and Sidewinder air-to-air missiles. It is equipped with a rotating bomb door and electronic reconnaissance equipment. McDonnell.

F–102 Delta Dagger. An all-weather fighter-interceptor, built for ADC, this was the first aircraft to incorporate the area rule (wasp waist) design. It is delta winged, J–57 engine powered, and has an advanced electronic fire-control system which seeks out target at long range, directs correct intercept course, and automatically fires weapons (missiles or rockets). Span 38′, length 68′5″, height 21′3″, speed supersonic, ceiling above 50,000′, range beyond 1,000 mi. Convair.

F–104 Starfighter. This tactical fighter and interceptor is used by both ADC and TAC. Its unusually short wings extend only 7½ feet from the fuselage. A J–79 engine with afterburner provides over 16,000 pounds of thrust, and permits a climbing speed equal to its speed in level flight. It established a number of records, including time-to-climb of 15 minutes 4.5 seconds from takeoff to 98,424 feet, and altitude record of 103,395 feet, in December 1959. Varied armament possibilities include 20 mm. T-171 Vulcan six-barrel "Gatling" guns, and AAM–N–7 (GAR–8) Sidewinders. A unique feature is the first automatic downward ejection seat incorporated in production-type fighters: after the release handle is pulled, (*a*) cockpit is depressurized and control column stored away, (*b*) parachute shoulder harness is tightened, pilot's legs are pulled together and ankle-clamped in place, (*c*) explosive cartridge blows escape hatch and ejects seat downward and out, (*d*) pilot's seat belt is unsnapped, freeing him from seat, and (*e*) parachute opens at preset altitude. Span 21′11″, length 54′9″, height 13′6″, speed over 1,400 mph, ceiling above 90,000′, range beyond 1,000 mi. Lockhead.

F–105 Thunderchief. Built for Tactical Air Command, this supersonic fighter-bomber is classed as a weapon system, with all integral components designed as a unified whole. It can deliver both HE and nuclear bombs and rockets at very high speeds over long ranges. An electronic system permits pinpoint bombing from extremely low level to over 50,000 feet. The bomb bay is longer than that of the World War II B–17 Flying Fortress. It set a closed-course speed record in December 1959 of 1,216.48 mph. Armament includes Vulcan cannon, rockets, and air-to-air missiles. Span 34′11″, length 63′1″, height 19′8″, speed supersonic, ceiling above 55,000′, range beyond 1,500 mi. Bomb load is 2 tons. Republic.

F–106 Delta Dart. Evolved from the F–102, this all-weather mach 2 interceptor exists in both single-seat and tandem-seat versions. Fire-control and

guidance systems are capable of automatically flying the aircraft through any kind of weather, day or night, under direction of ground control intercept stations. In December 1959 it set a world's straightaway speed record with a two-way average of 1,520.9 mph. It is the highest flying all-weather interceptor. A J–75–9 turbojet with after-burner provides 23,500 pounds of thrust. Span 38′, length 70′8″, height 20′3″, speed over 1,500 mph, ceiling above 50,000′, range 1,500 mi. Armament: GAR–3 or –4 Falcons, MB–1 Genie with nuclear warhead. Convair.

H–19 SIKORSKY HELICOPTER. Used by all major USAF commands, the H–19 is readily adaptable for passenger transport (12 seats), cargo (2,500 pounds), mail, rescue, or evacuation work. Blade 53′, length 41′2″, height 15′6″, speed over 100 mph, ceiling above 12,000′, range beyond 500 mi. United.

H–21 WORKHORSE. This troop carrier helicopter has been through a number of modifications. Its major use is as a cargo or evacuation craft, and it can carry 20 troops or 12 litter patients and attendants. Blade 44′, length 52′6″, height 14′6″, speed 127 mph, ceiling above 20,000′, range variable, depending on auxiliary tanks. Vertol (Piasecki).

H–43 HUSKIE. This turbine-powered local-use crash rescue craft was produced for the Air Rescue Service. In December 1959 it set a world's altitude record for heavy helicopters of 30,100 feet. It is used by all major USAF commands, can carry 7 passengers, or a ½-ton fire-fighting kit, or 2,500 pounds of cargo. Blade 51.5′, length 25′2″, height 12.7′, speed 120 mph, ceiling above 25,000′, range over 200 mi. Kaman.

KC–135 STRATOTANKER. A military adaptation of the Boeing 707 jet transport, the KC–135 was developed specifically to serve as an aerial refueling tanker, and hence is in a class by itself, not usually considered as merely a K-modification of a cargo aircraft. Powered by four J–57 engines in the 10,000 pound thrust class, it has set a number of long distance records. Capacity of over 23,000 gallons. Span 130′10″, length 136′3″, height 38′5″, speed over 600 mph, range beyond 4,500 mi. Boeing.

SA–16 ALBATROSS. Extremely versatile and dependable aircraft, the Albatross is used in search and rescue operations around the world by the Navy and Coast Guard (as UF–1), as well as USAF commands. It is a twin engined, propeller-driven triphibian (i.e., wheels, pontoons, and sprung skis for ice and snow). The "B" model has larger wings and slightly longer fuselage. The cabin may be adapted for various missions. Crew: 4 to 6. It can carry 12 stretcher cases and two medical attendants, or as a transport, 10 passengers in addition to crew. With seats removed, it may be used for cargo or for other special missions. It carries auxiliary power plant for emergency apparatus. SA–16A: span 80′, length 60′8″, height 24′3″, speed over 240 mph, ceiling 25,000′, range 2,500 mi. SA–16B: span 96′6″, length 62′4″, height 26′11″, speed and range above "A" model, and increased single-engine operation. Grumman.

T–29 FLYING CLASSROOM. The trainer version of the C–131 (see above) is used for bombardier/navigator/radar operator training and proficiency. It has 14

fully equipped stations for students, plus radio operator's station, 4 astrodomes, 5 driftmeters, 18 radio antennae, radome, and periscopic sextant facility. Each student station has map table, loran scope, altimeter indicator, and radiocompass panel. T–29D's have heavier, more complex "K" bombing system equipment, and facilities for only six students. Other than "D" models carry crew of two, plus 14 students and two instructors. Specifications as for C–131.

T–33 SHOOTING STAR. More familiarly known as the "T-Bird", this is the trainer version of the F–80, first operational jet fighter in USAF. It is widely used throughout Air Force for proficiency flying and administrative flights. Powered by a J–33–A–35 turbojet engine, it features dual controls, tandem seating, and ejection seats. Span 38′10″, length 37′8″, height 11′8″, speed 600 mph, ceiling above 45,000′, range beyond 1,000 mi. Lockheed.

T–37 PRIMARY TRAINER. Produced specifically for use by ATC, this was the first jet trainer initially so designed. It has side-by-side seating for instructor and student. It was specifically designed to give primary students the "feel" of jet flying, with in-flight characteristics almost identical with those of high-speed tactical aircraft while still providing a high margin of safety. It is equipped with ejector seats and jettisonable canopy, standardized cockpit layout with flaps, brakes, trim-tabs, radio controls, etc., located and operated as in standard USAF tactical aircraft. Span 33′10″, length 29′4″, height 9′5″, speed 350 mph, ceiling 35,000′, range about 600 mi. Cessna.

T–38 TALON. Powered by two J–85 or J–83 turbojet engines, this supersonic jet pilot trainer was produced to supplant the T–33 as an advanced trainer. Also it is used for general training in supersonic pilotage techniques, multijet operation, aerobatics, etc. Span 25′4″, length 43′5″, height 11′11″, speed 850 mph, ceiling above 55,000′, range beyond 1,150 mi. Northrop.

T–39 SABRELINER. While produced for utility and as a trainer, it is also suitable for single-pilot operation. When used as other than a trainer, it has a capacity of 4 to 8 passengers. It has twin jet J–60–P engines, swept-back wings, cabin pressurized at 8,000 feet to altitude of 45,000 feet. Span 42′6″, length 43′9″, height 15′6″, speed over 500 mph, ceiling above 45,000′, range beyond 1,000 mi. North American.

U–2. This research and special reconnaisance aircraft has a single turbojet engine. Unusually long slender wings use special droppable outrigger balancer wheels on take-off. Span 90′, length 45′, speed and range classified, ceiling above 60,000′. Used by NASA as well as USAF. Lockheed.

U–3A. Also known as L–27A, this twin-engine, propeller-driven cabin monoplane seats five, including pilot. It is used for administrative liaison and light cargo missions. Span 36′1″, length 27′1″, height 10′5″, speed 230 mph, ceiling 20,000′, range beyond 1,000 mi. In January 1961, the USAF accepted delivery of the first operational U–3B. This advanced model has refinements which increase its range to over 1,400 mi. and give it all-weather capabilities. Cessna.

APPENDIX B

Missiles and Rockets

The following list of best known military combat-type missiles and rockets has been arranged by category, i.e., surface-to-surface, air-to-surface, surface-to-air, and air-to-air.

Since most missiles and rockets are more popularly known by their names than by their official weapon system designations, subcategorization by name has been used. Some Army and Navy weapons which may conceivably be considered integral contributions to the aerospace effort have also been included.

This list is presented as a convenience to the student, and is not to be considered as a complete inventory of the missiles and rockets available to the Armed Forces of the United States. The statistical data has been gathered from unclassified sources and do not necessarily represent official Department of Defense performance specifications.

SURFACE-TO-SURFACE

Atlas SM–65. This first United States ICBM is a one and one-half stage, liquid fueled, 400,000 lb. thrust, rocket missile. It has one sustainer and two twin-chambered boosters, plus two small vernier engines to prevent roll. Boosters are jettisoned after launch. Usual fuel: liquid oxygen and hydrocarbon RP–1. The Atlas is the versatile workhorse of the ICBM fleet and is capable of, and a favored vehicle for, placing satellites in orbit. With nuclear warheads, it is an operational weapon system (WS–107A–1) which, in its E model, uses all-inertial guidance. The missile itself, without ground equipment, has almost 50,000 parts and components within its stainless steel shell. Launch weight: 260,000 lbs.; payload: 3,000 lbs.; speed 18,000 mph; ceiling about 600 mi.; range over 8,000 mi.; 75′ to 82′ long; 10′ in diameter. Each missile costs approximately $2 million. Primary using command: SAC. Primary contractor: Convair Division, General Dynamics Corp.

Corporal SSM–A–17. The U.S. Army's long range tactical missile, this weapon is also designated M–2. It is a supersonic ballistic missile which offers a field commander great firepower for use against selected targets deep behind enemy lines. Length, 46′; diameter, 30″; launch weight, 12,000 lbs.; range, up to 90 mi.; altitude, 20–30 mi.; velocity, mach 3; thrust, 20,000 lbs.; fuel mono-ethyanaline and red fuming nitric acid. Using either a nuclear or high explosive warhead, the missile is fired from a mobile launcher which can be set up in 6 hours. Deployed in Europe, Corporal battalions usually have approximately 250 men, and consist of two batteries, each of which is equipped with five self-propelled launchers and support vehicles. Primary contractor: Firestone.

HONEST JOHN M–31. An Army tactical rocket, this free-flight ballistic missile is capable of carrying either a nuclear or HE warhead. Range, approximately 12 mi.; mach 1.7 speed; length 27′; diameter 30″; launch weight 5,800 lbs. Each costs approximately $11,600. Fired from a self-propelled mobile launcher, using a solid fuel, and no electronic controls, this missile offers many advantages in mobility and simplicity. A more advanced version, the M–50, is made of aluminum, weighs 1,000 lbs. less, and is a few inches shorter. Launch crew: 5 or 6. Developed by Redstone Arsenal, production models by Douglas.

JUPITER SM–78. This strategic, nuclear-warhead, all-inertial guided, single-stage intermediate range ballistic missile developed by the Army's Redstone Arsenal was given to the Air Force in November 1956 before it was successfully fired. The first successful free world IRBM, it was used as the vehicle for the first full-scale nose cone to be recovered after transatmospheric flight. Using command: SAC. Operational squadrons have been established in both Italy and Turkey as part of NATO. Length 60′; diameter 105″; speed 10,000 mph; range beyond 1,500 mi.; thrust 150,000 lbs.; launch weight 110,000 lbs.; ceiling (apogee) about 350 mi. It uses liquid oxygen and kerosene (hydrocarbon RP–1).

LACROSSE SSM–A–12. Alternate designation: M4E2. Initially operational in 1959, this highly mobile guided missile is the equivalent of the replaced long range artillery pieces of past wars. Fired from a modified Army truck, it can carry either HE or nuclear warheads on command guidance. Length 19′; wingspan 108″; diameter 20½″; launch weight 2,300 lbs.; range 12–30 mi.; altitude about 3 mi.; speed transonic. Solid propellant. Production model by Martin.

LITTLE JOHN M–31. Highly mobile and simple, easily airlifted (launch weight about 760 lbs.), using light-weight launching apparatus, this free-flight ballistic missile has a destructive power greater than that of heavy artillery. A solid-propellant, 12½″ rocket, about 14½′ long, it may be fired at ranges of up to 10 mi. at supersonic speed with either nuclear or HE warhead. Primary contractor: Emerson Electric.

MACE TM–76. This air-breathing tactical missile was first operationally deployed with units of USAFE in Germany in the spring of 1959. A much improved, advanced version of the Matador TM–61, the Mace has already appeared in both "A" and "B" models. Both models use a turbojet engine, with solid-fuel rocket booster. Length 44′; span 22′; height 10′; range about 750 mi. ("B" model considerably greater); ceiling above 40,000′; launch weight about 10,000 lbs.; nuclear warhead. TM–76A has ATRAN guidance system, considered virtually unjammable; TM–76B uses inertial guidance system. Both models zero-launched (ZEL) from self-propelled mobile launcher. Primary contractor: Martin.

MATADOR TM–61. Originally known as the B–71 pilotless bomber, this tactical, air-breathing guided missile is in use with USAFE and PACAF units. It is powered by a turbojet engine plus solid-fuel booster. ZEL, span about 28′;

length about 40′; speed above 650 mph; range about 600 mi.; ceiling above 35,000′; warhead either nuclear or HE; launch weight about 10,000 lbs.; variable guidance systems, including MSQ radar line-of-sight controlling and "Shannicle," which uses a hyperbolic grid system similar to LORAN. Being replaced by Mace TM–76. Primary contractor: Martin.

MINUTEMAN SM–80. A "second generation" ICBM, using solid instead of liquid propellants, the Minuteman is designed to provide instantaneous massive SAC response to enemy attack. Smaller, lighter, and simpler than the Atlas or Titan, it is also comparatively low in cost and easy to maintain and operate. Readily launchable from either "hard" silos or special launcher railroad cars, it is not very vulnerable to enemy attack. In operational deployment it can be placed in its underground bombproof silo in readiness to fire upon receipt of a firing signal: presently the closest approximation of "pushbutton" warfare. Three-stage solid propellant rocket engines; all-inertial guidance; speed over 15,000 mph; range beyond 5,500 mi.; ceiling approximately 700 mi. (apogee); dimensions classified; nuclear warhead. Primary contractor: Boeing.

PERSHING. This is a solid propellant tactical missile developed under the supervision of the Army Ballistic Missile Agency, smaller, lighter, and more mobile than the Redstone, which it will replace. It was developed for mobility, reliability, short reaction time, simplification of support equipment, and versatility in all types of terrain and climate. First successfully fired in February 1960. Although specifications are still classified, the following "guesstimates" have been made in unofficial publications: length about 32′; diameter 35–40″; range 350–400 mi.; speed supersonic; fuel, solid propellant; two-stage; inertial guidance; nuclear warhead. It is the epitome of the Army "shoot and scoot" principle for modern artillery. Primary contractor: Chrysler.

POLARIS FBM (Fleet Ballistic Missile). This submarine or surface ship-launched intermediate range ballistic missile's most obvious advantages are extreme mobility and difficulty of detection prior to launching. Specially designed submarines each carry 16 missiles, to be launched either on or below the surface; below, the missile is ejected from its launching tube in a submerged vessel by inert gases which propel the missile above water, where its rocket motor ignites. A special system, known as Ship's Inertial Navigational System (SINS), has been devised to achieve accurate navigation without celestial fixes; this is needed to obtain accurate positional data by the launching vessel's crew. Once in flight, the missile is also kept on course by an inertial guidance system. Length about 28′; diameter 4½′; range over 1,200 mi.; speed about 8,000 mph; altitude about 400 mi. (apogee); launch weight about 28,000 lbs.; two-stage solid propellant; nuclear warhead. More advanced models with greater range are under development. The Polaris became operational from undersea craft in 1960. Primary contractor: Lockheed.

REDSTONE SSM–A–14. This Army tactical missile was initially operational in 1958, and was deployed with troops in Germany. It has both HE and nuclear capability. Length 69′; diameter 70″; range about 200 mi.; speed mach 5; launch weight 61,000 lbs.; apogee 55 mi.; thrust 75,000 lbs.; fuel, liquid

oxygen, ethyl alcohol, and water. Being replaced by the solid-fuel, longer-range Pershing, Redstone missiles are being used by NASA for Project Mercury equipment test flights. Primary contractor: Chrysler.

REGULUS I SSM–N–8. An air-breathing attack missile resembling a swept-wing jet fighter, initially operational in 1954. Production ceased in 1958. Length 33′; diameter 54″; wingspan 21′; speed about 600 mph; range 500 mi.; turbojet power plant with solid propellant booster; radio command guidance system; nuclear warhead. Primary contractor: Chance Vought.

REGULUS II SM–N–9A. Designed as replacement for Regulus I, this cruise-type air-breathing missile was primarily conceived as a submarine-launched missile with IRBM capability. The production program was cancelled after the missile was declared obsolescent in December 1958, but a number of operational missiles may still be found in fleet use for years to come. Length 59′; diameter 72″; span 20′; range beyond 800 mi.; speed beyond mach 2; ceiling over 65,000′; radio command guidance system; nuclear warhead; turbojet plus solid propellant booster. Primary contractor: Chance Vought.

SERGEANT SSM–A–26. This solid-propellant ballistic guided missile was developed to replace the Corporal. Length 36′; diameter 31″; range 75 mi.; speed supersonic; launch weight 10,000 lbs.; inertial guidance; HE or nuclear warhead. Primary contractor: Sperry Utah Engineering.

SNARK SM–62. Once known as the B–62 pilotless bomber, the Snark was the first long range SAC bombardment missile. It has a self-contained, non-jammable, stellar-monitored guidance system with a proved high degree of accuracy over long range. From ZEL launching, it has repeatedly been test flown over distances of up to 5,000 miles. Length 69′; span 42′; height 15′; speed about 600 mph; range 5,500 mi., launch weight 59,000 lbs. Cost is about one-tenth that of a manned bomber. The first operational wing of Snarks was activated at Presque Isle AFB, Maine, in 1958. With an accuracy unprecedented in the field of fully automatic weapons, Snark has proved it can approach a target from any direction, sneaking in at very low altitude to avoid conventional radar warning systems in a manner so far impossible with regular ballistic missiles. Attaching auxiliary fuel tanks to Snark's wingtips could extend the range to as far as 7,000 miles. Mobility is demonstrated by capability of being transported in C–124, C–132, and C–133 aircraft. Detachable wings aid in storage during transport. Up to 20 can be launched within 24 hours from each site of three launching pads. In its terminal phase, the vehicle becomes supersonic and has an excellent electronic countermeasure capability against defensive missiles. Capable of carrying a very large nuclear warhead, Snark is superior to ballistic missiles in almost every feature except speed. It can even be recalled; in one test flight it was fired 1,300 miles down-range and then returned to land at the launching site. Primary contractor: Northrop.

THOR SM–75. An intercontinental ballistic missile (WS–315–A), it is in operational use by SAC and Britain's Royal Air Force. It is also used as the first stage for space probes. Length 62′; diameter 8′; speed mach 15; range beyond

1,500 mi.; apogee 350 mi.; launch weight over 90,000 lbs.; all-inertial guidance system; thrust 150,000 lbs.; fuel, liquid oxygen and hydrocarbon RP–1. Limited (IRBM) range makes it more feasible for location in Europe than continental United States. Four RAF squadrons have been activated in the British Isles, where SAC-trained crews handle the missile. An operational squadron uses 15 Thors, all of which can be launched simultaneously from their combination transporter-erectors after a 15-minute countdown. The single-stage Thor has been used as the main propulsion system for nonmilitary experiments, including the historic 1958 lunar probe, the 1960 Pioneer V sun-orbiting satellite, and many others. Primary contractor: Douglas.

TITAN SM–68. A highly sophisticated ICBM (WS–107–A–2) with greater range and load-carrying capability than the Atlas, the Titan is a part of the SAC complex of weapons. Nestled in deep (155 feet) concrete-lined silos, the Titan is lifted to the surface by special elevators for launching. Length 90′; diameter 10′; launch weight 220,000 lbs.; speed 15,000 mph; apogee 920 mi.; range beyond 5,500 mi.; thrust, 1st stage 300,000 lbs., 2d stage 60,000 lbs.; fuel, liquid oxygen and hydrocarbon RP–1; guidance system, all-inertial or radio-inertial; nuclear warhead. Titan II is being developed to use storable propellants (Titan I, like the Atlas, must be fueled immediately prior to launch time). Primary contractor: Martin.

AIR-TO-SURFACE MISSILES

BULLPUP ASM–N–7A. Developed and produced for the Navy, it is also used by the Air Force (under the designation GAM–83A). Relatively inexpensive, highly accurate, and simple in design, it is used against comparatively small targets—tanks, pillboxes, truck convoys, bridges, trains, and marshaling yards. Length 11′; diameter 1′; weight 571 lbs.; range 4–6 mi.; speed supersonic; guidance by radio command; HE or nuclear warhead. Used by TAC jet aircraft; Marine Corps has also successfully fired the Bullpup from helicopters. It became operational in 1959. USAF began development of a radically improved version known as White Lance (GAM–79), but canceled continuation in favor of a new, improved Bullpup which replaces the original solid propellant with a prepackaged liquid fuel and improved guidance. The advanced Bullpup, a rugged and reliable weapon, will actually cost less and have greater destructive and penetration capability. Primary contractor: Martin.

CORVUS ASM–N–8. This Navy weapon is still under development and testing. A more sophisticated weapon for use against defended areas, little information is available from official sources. Unofficial "guesstimates" from usually reliable sources indicate that Corvus will be supersonic, propelled with prepackaged liquid fuel, have a range greater than 100 miles, carry either HE or nuclear warhead, and reportedly will penetrate highly defended areas by homing in on electronic equipment such as defense radar. Primary contractor: Temco Aircraft.

CROSSBOW GAM–67. A winged missile developed for the Navy by the Radioplane Division of Northrop Corp., this turbojet-propelled weapon has been

tested for use on B–47 and B–52 bombers. Further development is being phased into the Longbow (WS–121–B). Details are not available on either Crossbow or Longbow. Primary contractor for both is Northrop.

Hound Dog GAM–77. A long range supersonic ALBM (Air Launch Ballistic Missile) designed for launching from the B–52, this missile was developed from the Navaho project, abandoned in 1957. Length 42½′; diameter 28″; span 12′; launch weight about 10,000 lbs.; powerplant, J–57 turbojet with 7,500 lbs. thrust; nuclear warhead; range beyond 500 mi.; speed about mach 2; fuel JP–4; guidance system, all-inertial. Presently operational, it is expected to be replaced by the superior Skybolt. Primary contractor: North American Aviation.

Lazy Dog. A very small (2 inches long) antipersonnel missile. Designed to be dropped from low-flying aircraft, its main purpose is to harass enemy ground troops.

Quail GAM–72. The Quail, a diversionary missile, has the principal role of acting as a decoy to divert attacking enemy aircraft and missiles from our own bombers. Carried by B–47 and B–52 aircraft, the Quail can be released to take a different course. Its peculiar configuration causes radar returns which resemble those of the mother aircraft. Although not destructive in itself, Quail could carry a small warhead and serve as a nuisance on the ground after its fuel and flight are finished. Length about 12′; span about 2½′; launch weight about 1,100 lbs.; range about 200 mi.; speed near sonic, it is powered by a turbojet engine, and carries electronic countermeasure equipment to further confuse and divert enemy. It uses a gyro autopilot. Primary contractor: McDonnell Aircraft.

Rascal GAM–63. An early type of air-launched guided missile, the Rascal was designed for launching from SAC bombers approximately 100 miles from target. Length 32′; diameter 4′; span 15′; fuel, nitric acid and gasoline; speed supersonic; nuclear warhead; radio-command guidance system; three in-line liquid propellant engines; thrust 12,000 lbs. Primary contractor: Bell Aircraft.

Skybolt GAM–87A. Although considered by many to be an advanced version of the Hound Dog, Skybolt is actually an entirely different weapon. Unlike the air-breathing Hound Dog, Skybolt is a true ballistic missile like Atlas or Titan, with a two-stage, solid propellant power plant. Designed for launching from SAC B–47, B–52, and B–58 bombers, there is also a possibility it may be adaptable for use with the B–70. All data are classified. From educated "guesstimates," and some official statements, it is most likely that the missile is between 25 and 30 feet long, about 3 feet in diameter, weighs about 7,000 pounds, and has a range of over 1,000 miles at hypersonic speed. In one spectacular early test, Skybolt was launched from a B–47 over the Atlantic, soared to a programmed near-miss with satellite Explorer VI then at perigee 156 miles from the earth's surface, and then returned to impact about 1,000 miles from launch. The major significance of Skybolt is that it combines many favorable features of the ICBM's and IRBM's with extreme, three-dimen-

sional, mobility. Hence, it is virtually immune to an enemy's first strike, and can be launched in comparative safety. Primary contractor: Douglas.

WAGTAIL. This is a highly sophisticated tactical-support weapon about which little information can be released. The concept calls for use of retrorockets after launch to permit very low velocity while the guidance system adjusts to target. The advanced guidance system will then permit the weapon to climb over obstacles such as trees and hills, and attack from extremely low altitude. After the guidance system has adjusted itself, the primary power plant will ignite and increase the missile's velocity. Primary development contractor: Minneapolis-Honeywell Regulator.

SLAM. Under study and development, the SLAM (Supersonic Low Altitude Missile) is reported to be capable of delivering a nuclear warhead as a low-altitude ALBM at high (mach 4) supersonic speed. Unofficial conjecture considers that SLAM will be powered by a nuclear ramjet propulsion unit. No primary contractor has been announced.

ZUNI. This is an all-weather, unguided free-flight, folding fin, solid propellant rocket developed by the Naval Ordnance Test Station, China Lake, Calif. It is operational in the fleet on such aircraft as the F9F Cougar. As many as 48 Zunis can be carried in jettisonable launchers. Length 110″; diameter 5″; weight 107 lbs.; speed about mach 3; range about 5 mi. It has an HE warhead, with variable types: fragmentation, flares, armor-piercing.

SURFACE-TO-AIR MISSILES

BOMARC IM–99. A long range area-defense guided interceptor missile which can be launched 120 seconds after receipt of warning signal, the Bomarc was developed specifically for interception and destruction of enemy aircraft and missiles before they approach target areas. Bomarc is controlled by SAGE. Unlike other types of aerospace defense missiles, Bomarc is guided from the ground only to altitude and the general target area, whereupon Bomarc's own target-seeker takes over. Armed with a proximity fuze, Bomarc does not have to collide with the target to achieve destruction. USAF has announced 14 locations for Bomarc sites, with each squadron expected to have 60 missiles. Tests for accuracy have been excellent (e.g., a supersonic Regulus II was destroyed in a direct hit 160 miles downrange at 40,000 feet within 7 minutes after launch alert was received). Using two ramjets and a booster, each with 50,000 lbs. thrust, Bomarc has a mach 3 speed. Length 47′; span 18′; height 10′; ceiling above 60,000′; range IM–99A 250 mi., IM–99B over 400 miles; HE or nuclear warhead; launch weight 15,000 lbs. The IM–99A booster uses inhibited red fuming nitric acid and unsymmetrical dimethyl hydrazine mixture; IM–99B booster uses a solid propellant. Primary contractor: Boeing.

HAWK SAM–A–18. This is a highly mobile, two-stage Army weapon designed specifically for use against low-flying aircraft. Length 16.8′; diameter 14″; span 48″; speed mach 2, ceiling from less than 100′ to over 38,000′; launch weight 1,275 lbs.; warhead HE; solid propellant; range about 20 miles; guidance by semi-active radar homing. It is used by both Army and Marine Corps

field units. Support equipment is simple, rugged, easily maintained, and readily air transportable by helicopter or medium aircraft. Missile batteries normally have 36 missiles mounted on 12 triple-weapon launchers. Primary contractor: Raytheon.

NIKE-AJAX SAM–A–7. This first supersonic anti-aircraft guided missile designed to intercept and destroy target aircraft regardless of evasive action has been operational since 1953. Over 10,000 were produced before production was halted. It is a two stage missile, the sustainer using nitric acid and JP–4 jet fuel, and the separable booster using solid propellant. Length 31′; diameter 12″; span 52″; ceiling 60,000′; range 25 mi.; speed supersonic; warhead HE; launch weight 2,300 lbs.; guidance by command. It is being replaced by the more advanced Nike-Hercules. Primary contractor: Western Electric (airframe and launcher by Douglas).

NIKE-HERCULES SAM–A–25. Many times more effective than its predecessor, Nike-Ajax, Nike-Hercules has an anti-missile capability and carries either HE or nuclear warhead. Length 39′; diameter 31½″; span 90″; ceiling over 150,000′; range beyond 75 mi.; speed supersonic; launch weight 10,000 lbs.; guidance by command. Both sustainer and booster engines have solid propellant. Nike-Hercules units have been given the task of defending SAC bases from enemy attack. In tests it has successfully engaged and destroyed target drones traveling more than 2,000 mph, and parachute targets at above 150,000 feet: the fastest and highest targets engaged by aerospace defense weapons in the free world. Nike-Hercules has been operational since June 1958. Primary contractors: Western Electric and Douglas.

NIKE-ZEUS. Still in the development and testing stage, Nike-Zeus is not yet operational. It is being developed specifically as an anti-missile missile. Such progress was made that research into other projects, such as the Air Force Wizard program, was canceled, and attention devoted to this solid-propellant weapon. Although very little official information has been released, the following "guesstimates" have been made in usually reliable unofficial publications: length about 65′; diameter about 5′; range between 250 and 300 mi.; ceiling about 200 mi.; speed mach 4; thrust about 450,000 lbs.; guidance, integrated command. Primary contractors: Western Electric and Douglas.

REDEYE. Developed for use by ground forces against low-flying aircraft, the Redeye is a shoulder-fired, solid-propellant, Bazooka-type missile which is still being perfected. Equipped with an infrared homing device, it is about 4 ft. long, about 3 in. in diameter, and weighs about 20 lbs. It can be fired by an individual soldier. Primary contractor: Convair Division, General Dynamics Corp.

TALOS SAM–N–6. Designed to protect naval units from air attack, the Talos may also be used against surface targets. The U.S.S. *Galveston* (CLG–3), which is a guided missile cruiser commissioned in 1958, uses the Talos as its principal armament. Using a solid propellant booster at launch, Talos is sustained by a ramjet engine using kerosene and ambient air as fuel. Length about 30′; diameter about 30″; launch weight 3,000 lbs. plus the 4,000-lb.

separable booster in the first few seconds of flight; range over 65 mi.; speed supersonic; extremely high altitude ceiling; warhead HE or nuclear; guidance is in two stages: beam riding and passive homing. Improvements on the Talos system have led to the development of a new weapon, the Typhoon. Now in the development stage are two versions: the Long Range Typhoon (formerly called the Super Talos) and the Medium Range Typhoon (formerly called the Super Tartar). Both are being developed as anti-missile missiles to intercept both incoming tactical missiles and missiles launched from enemy submarines within seconds of their launching. The Typhoons are being developed for the Navy by Westinghouse. Primary contractor of Talos is Bendix.

TARTAR MARK 15. This solid propellant, beam-riding anti-aircraft missile is replacing 5-inch guns on cruisers and destroyers. HE warhead; length 15′; diameter 18″; span 3′; range 1 mi.; speed mach 2; weight 2,475 lbs.; two-stage propulsion system. Primary contractor: Convair Division, General Dynamics Corp.

TERRIER SAM–N–7. This is a supersonic guided missile suitable for use from shipboard, or for beachhead operations with Marine Corps. Length 15′ (27′ with booster); diameter 1′; weight 2,500 lbs.; HE warhead; solid fuel rocket booster and sustainer; speed supersonic; range 10 mi.; high altitude ceiling; guidance by beam riding. In shipboard use, selection, loading, and launching are integrated in an automatic system; on land, mobile launchers are used for anti-aircraft protection. A later model, Terrier II, incorporating advanced guidance features and greater coverage, is in production. It has twice the range and half again the speed of Terrier I. Terrier II is operational. Upon complete conversion, it will be used on 3 carriers, 3 cruisers, 3 guided missile cruisers, 1 guided missile destroyer, and 20 guided missile frigates. Primary contractor: Convair Division, General Dynamics Corp.

AIR-TO-AIR MISSILES

EAGLE AAM–N–10. Developed for the Navy, this missile represents a new approach to air-launched guided missiles in that the launching aircraft is designed to be a low-speed type, such as the A2F fighter. The missile itself will have an exceptionally long range for AAM types. Although there is very little advance data from official sources, the missile is expected to have a range of over 100 miles, a speed of over mach 3, length of approximately 15 feet, weight of about 1 ton, HE or nuclear warhead, solid propellant, and radar homing guidance system. Primary contractor: Bendix.

FALCON. This name is applicable to a family of Guided Air Rockets. Odd-numbered GAR's use radar homing devices, while even-numbered GAR's use an infrared homing guidance system. The Falcon-type supersonic rockets are among the smallest missiles in production. They can be carried either internally or externally on interceptor aircraft. Armed with conventional warheads in regular use, even unarmed test versions have destroyed drone targets. Operational with ADC aircraft since 1957, the Falcons are approximately 6′ long, 6½″ in diameter, with a 20″ span of fins. The launch weight is over 100

lbs., range beyond 5 mi., ceiling above 50,000′, and with a speed of mach 2. The GAR–11 is nuclear-tipped: the first air-to-air guided weapon with nuclear capability. All use solid ammonium perchlorate polysulfide propellants. Primary contractor: Hughes Aircraft Co.

GENIE MB–1. A supersonic, free-flight vehicle, considerably heavier than its Falcon cousins, Genie carries a nuclear warhead. Length 115″; diameter 17″; range about 6 mi.; speed mach 3; ceiling above 50,000′; weight about 800 lbs.; solid propellant. Genie was declared operational in January 1957 on ADC's F–89J, is presently mounted on F–101s, F–102s, and F–106s. Development is in progress to provide Genie with guidance and a liquid-propellant power plant. Primary contractor: Douglas.

MIGHTY MOUSE FFAR. This unguided rocket was developed by the Navy but is now considered standard on both Navy and USAF fighters. Solid propellant, folding-fin, HE-tipped, proximity-fuzed, it has the destructive force of a 75 mm. cannon shell, costs about $65. Length 4′; diameter 2¾″; weight 18½ lbs. Very versatile: it may be used for air-to-surface tactical operations against small targets by inserting different warheads for the purpose desired (armor-piercing, contact, proximity, etc.). Fired from launchers, as many as 194 have been successfully salvoed at the same instant. Primary contractor: Hunter-Douglas Division of Bridgeport Brass Co.

SIDEWINDER AAM–N–7. The most widely used AAM in the U.S. Fleet, it is also a standard weapon for the Marine Corps and the USAF. The USAF designation is GAM–8. It is also widely used by U.S. allies, notably Nationalist China, where it gave an excellent account of itself in combat over Formosa. Considered relatively inexpensive and reliable, it is in operational use on F–100s, F–101s, F–104s, and F–105s. Length about 9′; diameter 5″; span 2′; ceiling above 50,000′; speed supersonic; weight about 155 lbs.; HE warhead; solid propellant. The Sidewinder uses an infrared heat-seeking device which homes on the tailpipe of target aircraft. It is so accurate that it has destroyed target drones even when not equipped with a warhead. It is considered a member of the Falcon family. Sidewinder 1–C is being perfected as an improved version incorporating higher speed and greater range. It is used by both ADC and TAC. Primary contractor: Philco Corp./General Electric.

SPARROW III AAM–N–6. Developed from the obsolete Sparrow I and Sparrow II, it became Fleet operational in August 1958. Length about 12′; diameter 8″; weight about 380 lbs.; speed supersonic; ceiling over 50,000′; solid propellant; radar homing; HE warhead. An advanced version incorporates a new prepackaged liquid fuel engine system for higher performance capability. Primary contractor: Raytheon Manufacturing Co.

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